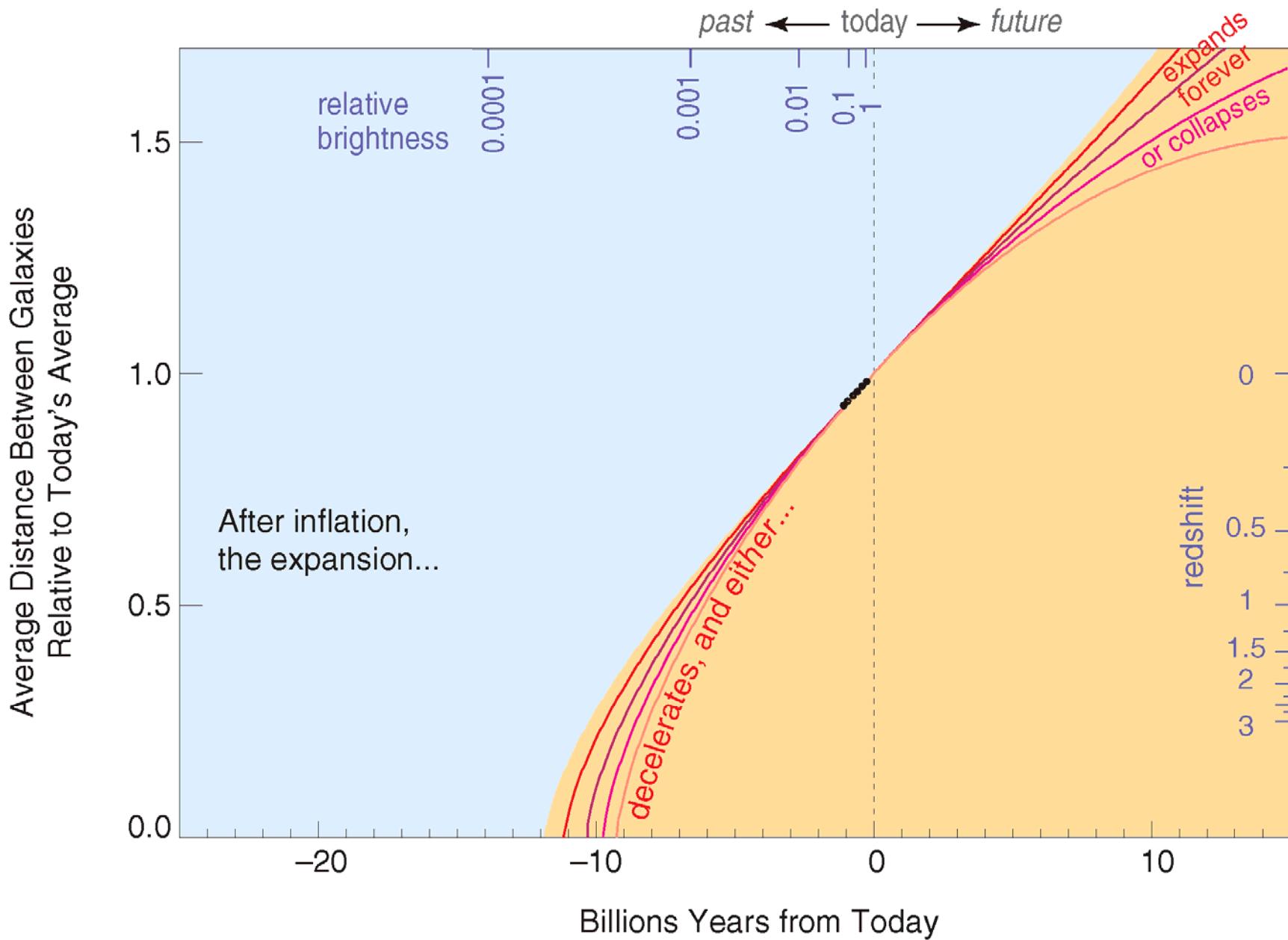


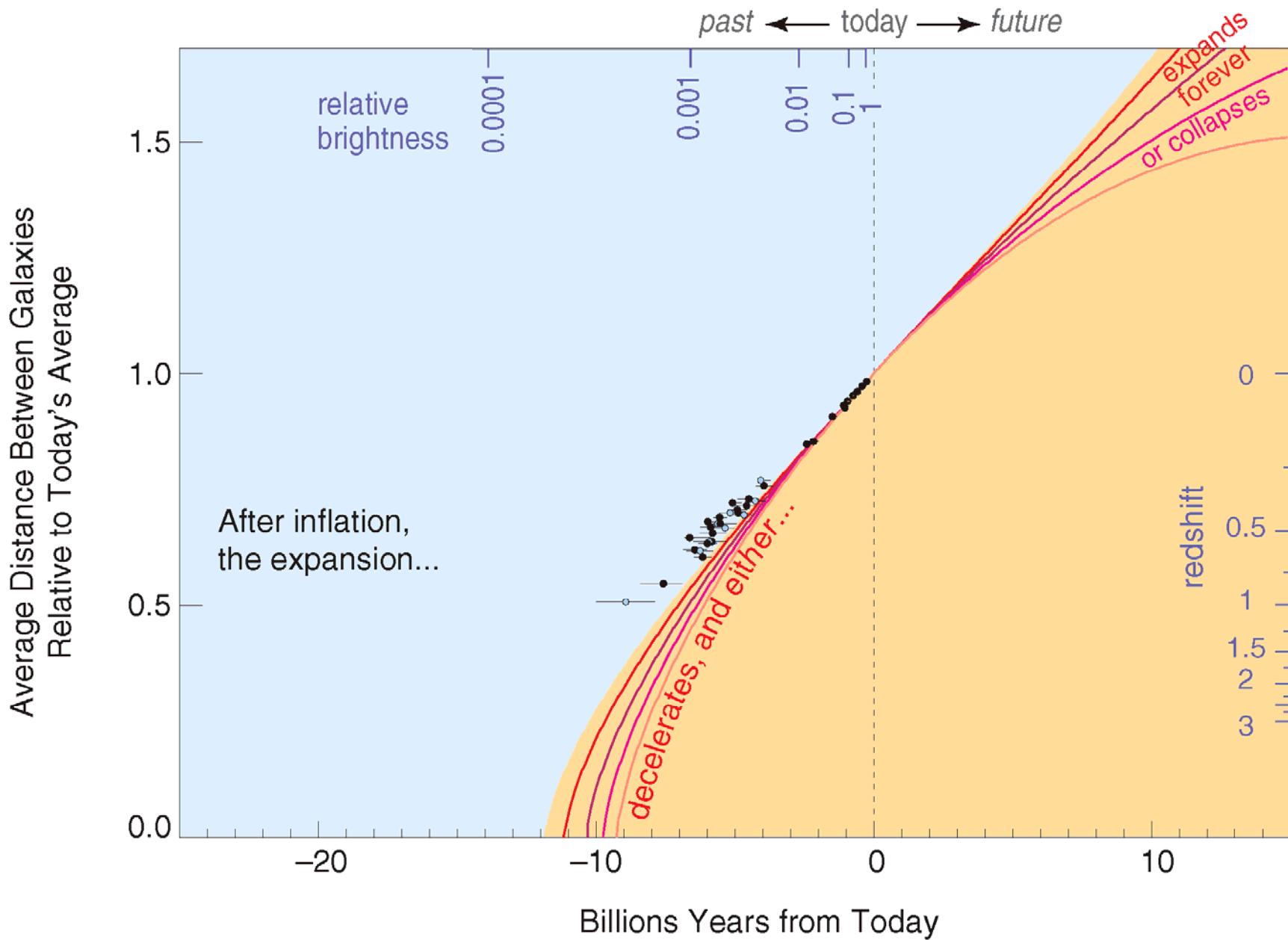
Physics Division Director's Review
**Observational Studies of Dark Energy:
Supernovae (& Baryon Oscillations)**

Saul Perlmutter
November 2005

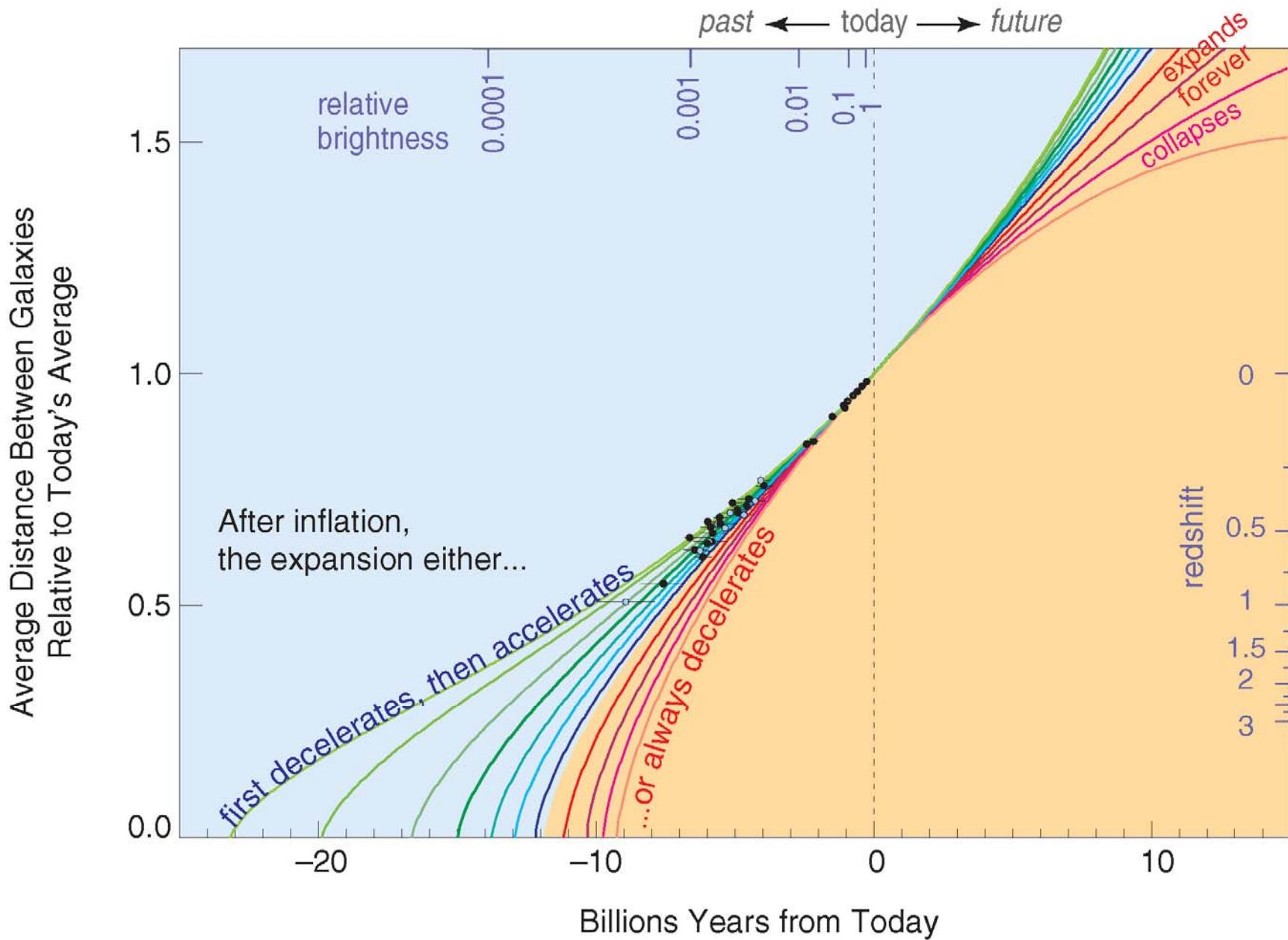
Expansion History of the Universe



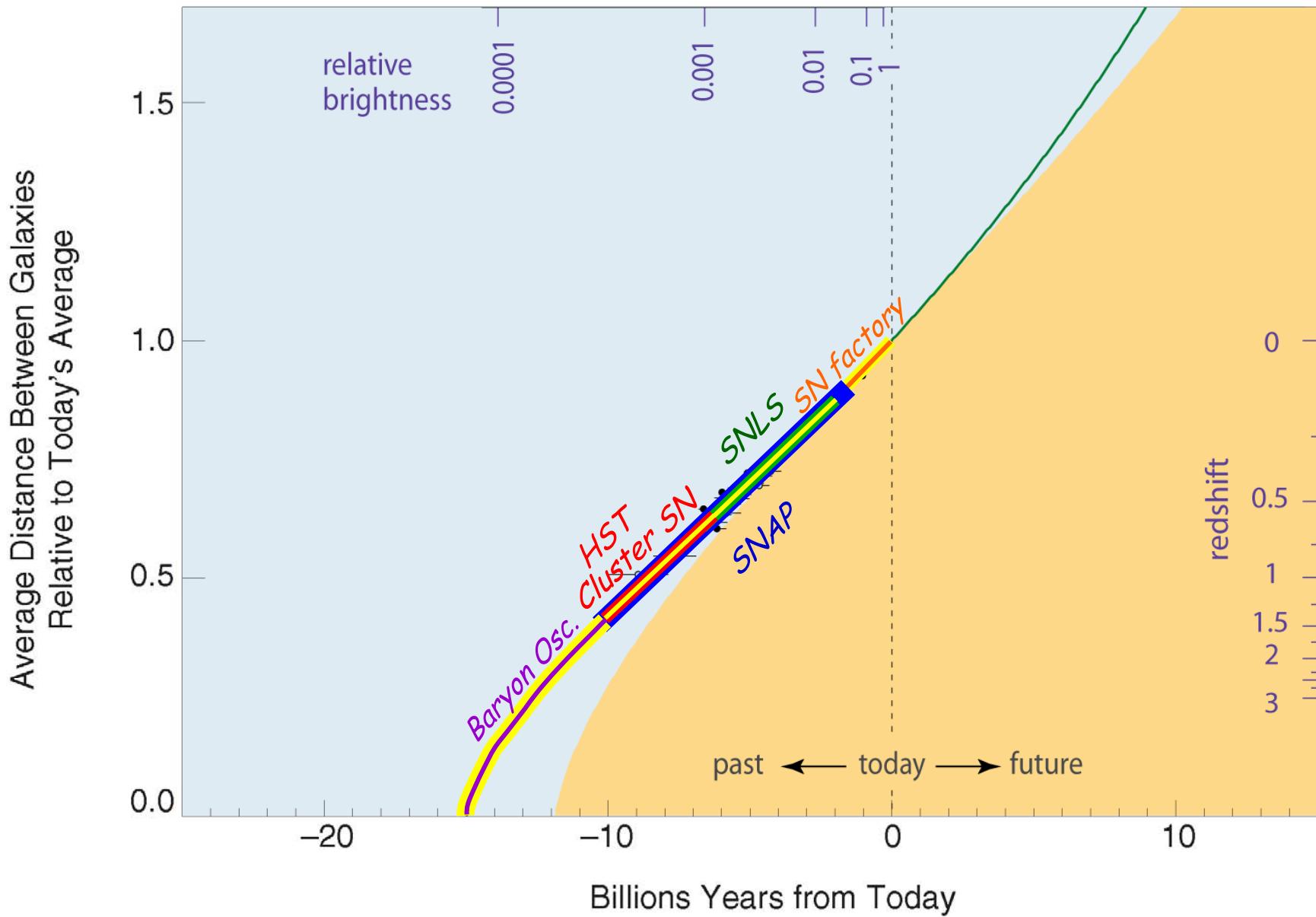
Expansion History of the Universe



Expansion History of the Universe



Expansion History of the Universe



Strategy:

$z = 0.02$

Statistics: Need more at base of hubble diagram.

Systematics: "Tune" and categorize the SNe Ia.

$z = 0.1$

Build a statistical sample that can be
-- divided into systematics subsamples
-- high enough quality for color correction of dust

$z = 0.9$

First probes of decelerating redshift range.
Look for basic trends and any "danger signs" before SNAP

$z = 1.7$

Low-z

Mid-High-z

Very-High-z

SN Cosmology Effort at LBNL 2005

Primary Effort on SCP

Faculty/Staff/Technical						Postdocs			Undergrads			
	SCP	SNF	SNAP		SCP	SNF	SNAP		SCP	SNF	SNAP	
R. Abiad			<input type="checkbox"/>	M. Lampton			<input type="checkbox"/>	S. Bailey		<input type="checkbox"/>	<input type="checkbox"/>	W. Chickering
G. Aldering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	W. Lee	<input type="checkbox"/>			S. Bongard		<input type="checkbox"/>		M. Fabricius
C. Aragon		<input type="checkbox"/>		M. Levi			<input type="checkbox"/>	K. Dawson	<input type="checkbox"/>	<input type="checkbox"/>		J. Fairfield
C. Bebek			<input type="checkbox"/>	E. Linder			<input type="checkbox"/>	L. Faccioli		<input type="checkbox"/>		A. Fathalizadeh
M. Bester			<input type="checkbox"/>	S. Loken		<input type="checkbox"/>	<input type="checkbox"/>	V. Fadeyev	<input type="checkbox"/>			S. Ferrell
W. Carithers		<input type="checkbox"/>	<input type="checkbox"/>	B. McGinnis			<input type="checkbox"/>	D. Kocevski		<input type="checkbox"/>		H. Ha
E. Commins			<input type="checkbox"/>	R. Miguel			<input type="checkbox"/>	M. Kowalski	<input type="checkbox"/>			A. Kulkarni
W. Craig			<input type="checkbox"/>	P. Nugent		<input type="checkbox"/>	<input type="checkbox"/>	N. Kuznetsova	<input type="checkbox"/>	<input type="checkbox"/>		D. Lamenti
C. Day			<input type="checkbox"/>	N. Palaio			<input type="checkbox"/>	B. Lee		<input type="checkbox"/>		F. Lau
P. Denes			<input type="checkbox"/>	D. Pankow			<input type="checkbox"/>	R. Scalzo		<input type="checkbox"/>		M. Meijer
R. DiGennaro			<input type="checkbox"/>	S. Perlmutter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	N. Suzuki	<input type="checkbox"/>			J. Saha
J. Emes			<input type="checkbox"/>	A. Pinar			<input type="checkbox"/>	R. Thomas	<input type="checkbox"/>	<input type="checkbox"/>		A. Uppula
G. Goldhaber	<input type="checkbox"/>			N. Roe	<input type="checkbox"/>		<input type="checkbox"/>	B. Weaver		<input type="checkbox"/>		D. Xu
D. Groom	<input type="checkbox"/>		<input type="checkbox"/>	R. Romano			<input type="checkbox"/>	Grad Students				
H. Heetderks			<input type="checkbox"/>	K. Runge			<input type="checkbox"/>	K. Barbary	<input type="checkbox"/>			
M. Hoff			<input type="checkbox"/>	D. Schlegel	<input type="checkbox"/>		<input type="checkbox"/>	S. Poon		<input type="checkbox"/>		
S. Holland			<input type="checkbox"/>	M. Sholl			<input type="checkbox"/>	D. Rubin	<input type="checkbox"/>			
P. Jelinsky			<input type="checkbox"/>	H. Shukla			<input type="checkbox"/>					
A. Karcher			<input type="checkbox"/>	J. Siegrist		<input type="checkbox"/>						
A. Kim			<input type="checkbox"/>	G. Smoot			<input type="checkbox"/>					
W. Kolbe			<input type="checkbox"/>	A. Spadafora	<input type="checkbox"/>		<input type="checkbox"/>					
W. Kramer			<input type="checkbox"/>	M. Strovink	<input type="checkbox"/>		<input type="checkbox"/>					
B. Krieger			<input type="checkbox"/>	J. Walder			<input type="checkbox"/>					
G. Kushner			<input type="checkbox"/>	L. Wang	<input type="checkbox"/>	<input type="checkbox"/>						
R. LaFever			<input type="checkbox"/>	G. Wang			<input type="checkbox"/>					

Primary Effort on SNfactory

Faculty/Staff/Technical							Postdocs			Undergrads			
	SCP	SNF	SNAP		SCP	SNF	SNAP		SCP	SNF	SNAP		
R. Abiad			<input type="checkbox"/>	M. Lampton			<input type="checkbox"/>	S. Bailey		<input type="checkbox"/>	<input type="checkbox"/>	W. Chickering	
G. Aldering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	W. Lee	<input type="checkbox"/>			S. Bongard		<input type="checkbox"/>		M. Fabricius	
C. Aragon	<input type="checkbox"/>			M. Levi			<input type="checkbox"/>	K. Dawson	<input type="checkbox"/>	<input type="checkbox"/>		J. Fairfield	
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M. Bester			<input type="checkbox"/>	S. Loken		<input type="checkbox"/>	<input type="checkbox"/>	V. Fadeyev	<input type="checkbox"/>			S. Ferrell	
W. Carithers	<input type="checkbox"/>	<input type="checkbox"/>		B. McGinnis			<input type="checkbox"/>	D. Kocevski		<input type="checkbox"/>		H. Ha	
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R. DiGennaro			<input type="checkbox"/>	S. Perlmutter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	N. Suzuki	<input type="checkbox"/>			J. Saha	
J. Emes			<input type="checkbox"/>	A. Pinar			<input type="checkbox"/>	R. Thomas	<input type="checkbox"/>	<input type="checkbox"/>		A. Uppula	
G. Goldhaber	<input type="checkbox"/>			N. Roe	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	B. Weaver		<input type="checkbox"/>		D. Xu	
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H. Heetderks			<input type="checkbox"/>	K. Runge		<input type="checkbox"/>		K. Barbary		<input type="checkbox"/>			
M. Hoff			<input type="checkbox"/>	D. Schlegel	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	S. Poon		<input type="checkbox"/>			
S. Holland			<input type="checkbox"/>	M. Sholl			<input type="checkbox"/>	D. Rubin	<input type="checkbox"/>				
P. Jelinsky			<input type="checkbox"/>	H. Shukla			<input type="checkbox"/>						
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A. Kim			<input type="checkbox"/>	G. Smoot			<input type="checkbox"/>						
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B. Krieger			<input type="checkbox"/>	J. Walder			<input type="checkbox"/>						
G. Kushner			<input type="checkbox"/>	L. Wang	<input type="checkbox"/>	<input type="checkbox"/>							
R. Lafever			<input type="checkbox"/>	G. Wang			<input type="checkbox"/>						

Primary Effort on SNAP

Strategy:

$z = 0.02$

Statistics: Need more at base of hubble diagram.

Systematics: "Tune" and categorize the SNe Ia.

$z = 0.1$

Build a statistical sample that can be
-- divided into systematics subsamples
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$z = 0.9$

First probes of decelerating redshift range.
Look for basic trends and any "danger signs" before SNAP

$z = 1.7$

Low-z

Mid-High-z

Very-High-z

Strategy:		Analyzing:	Running:	Planning:
$z = 0.02$	Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	<p>Nearby SN factory commissioning collecting data</p>
$z = 0.1$	Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	<p>SCP+Literature data: "Blinded" <i>CMAGIC</i></p>	<p>Dark Energy Survey</p> <p>SNAP</p>
$z = 0.9$	Very-High- z	<p>First probes of decelerating redshift range.</p> <p>Look for basic trends and any "danger signs" before SNAP</p>	<p>"Albinoni": first decelerating SN</p> <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	<p>HST search 2?</p> <p>SNAP</p>
$z = 1.7$				

Strategy:		Analyzing:	Running:	Planning:
$z = 0.02$	Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	Nearby SN factory commissioning collecting data
$z = 0.1$	Mid-High- z	Build a statistical sample that can be <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	SCP+Literature data: "Blinded" <i>CMAGIC</i>	Dark Energy Survey SNAP
$z = 0.9$	Very-High- z	First probes of decelerating redshift range. Look for basic trends and any "danger signs" before SNAP	"Albinoni": first decelerating SN <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	HST search 2? SNAP
$z = 1.7$				

	Strategy:	Analyzing:	Running:	Planning:
$z = 0.02$ Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	Nearby SN factory commissioning collecting data	SN factory upgrades?
$z = 0.1$ Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	SCP+Literature data: "Blinded" <i>CMAGIC</i>	SN Legacy Survey: first results	<p>Dark Energy Survey</p> <p>SNAP</p>
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$z = 1.7$				



Dust

Lensing

Optical
Atmosphere

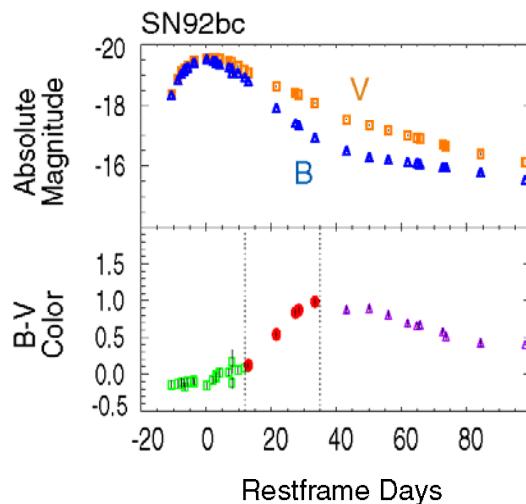


Filters

Optical IR
Detectors



Color-Magnitude Intercept Calibration Technique for Type Ia Supernovae



Wang, Goldhaber, Aldering, & Perlmutter (2003)



Dust

Lensing

Optical

Atmosphere



Filters

Optical

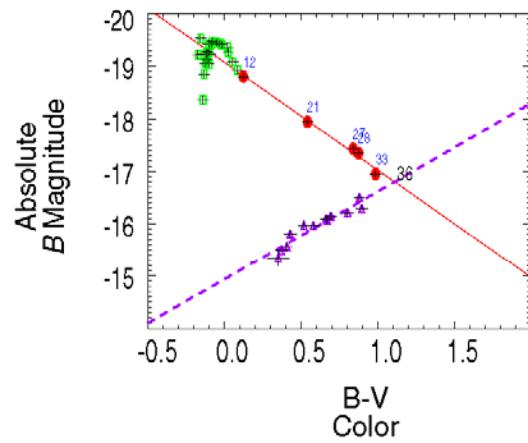
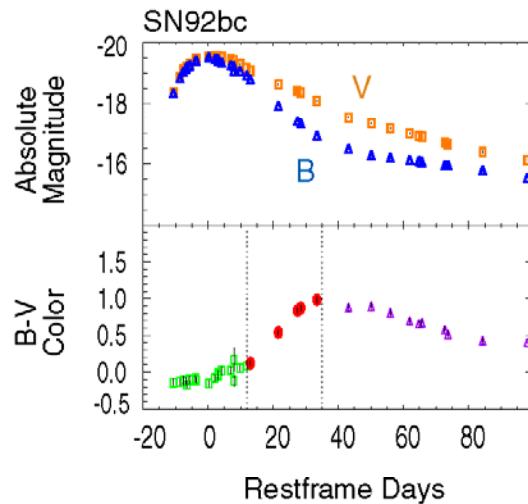
IR

Detectors



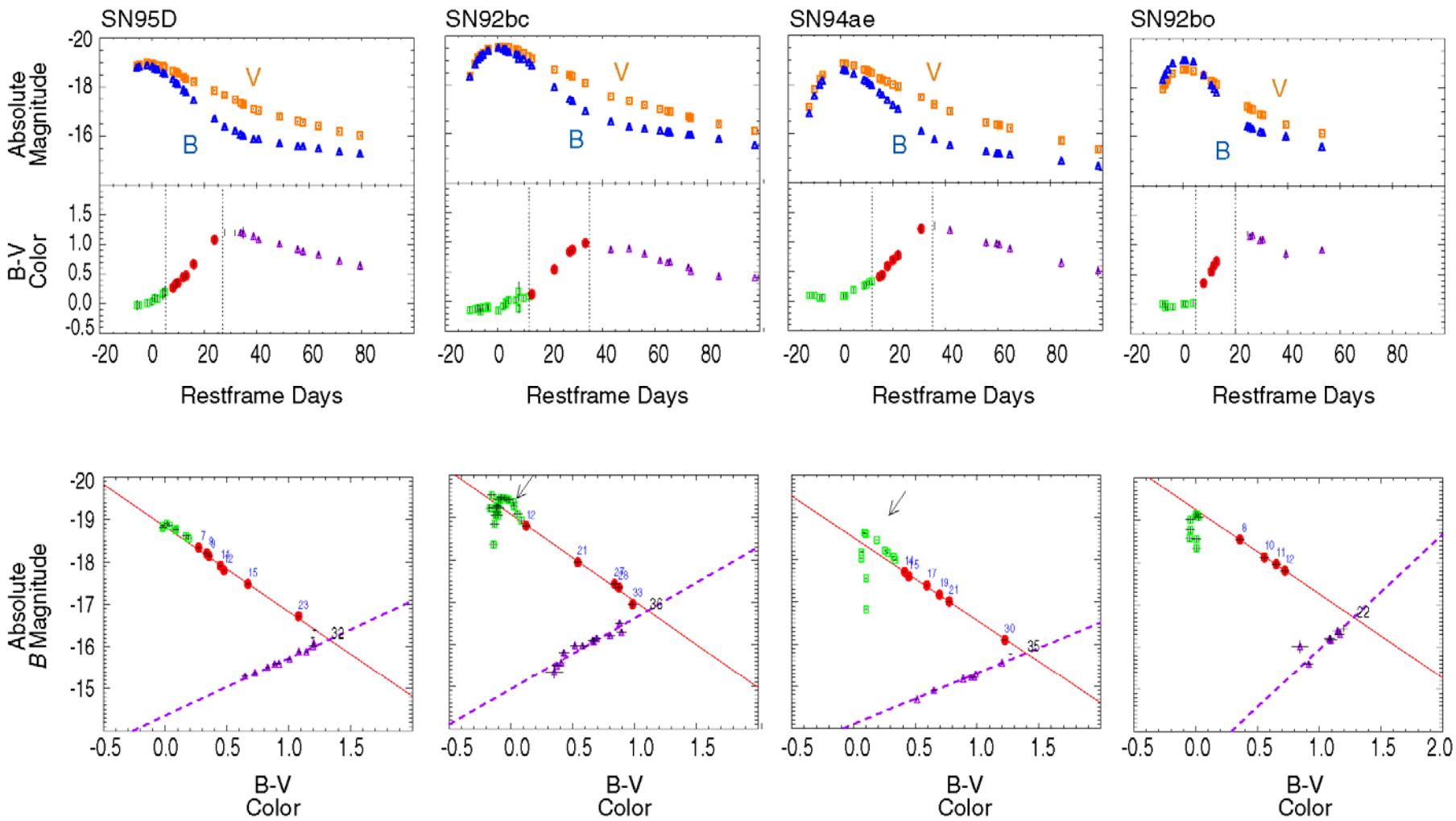
Interpretation

Color-Magnitude Intercept Calibration Technique for Type Ia Supernovae



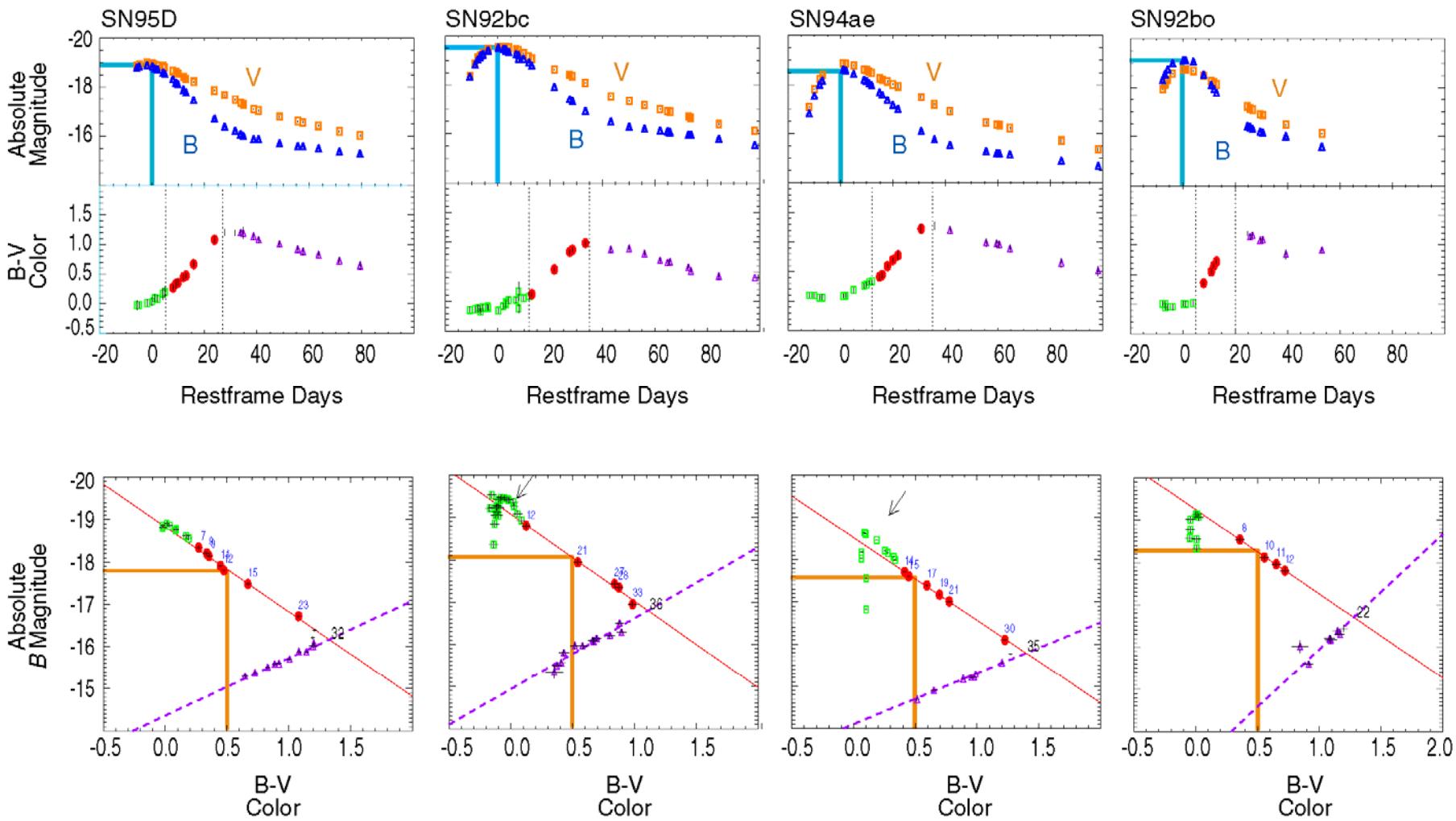
Wang, Goldhaber, Aldering, & Perlmutter (2003)

Color-Magnitude Intercept
Calibration Technique for Type Ia Supernovae



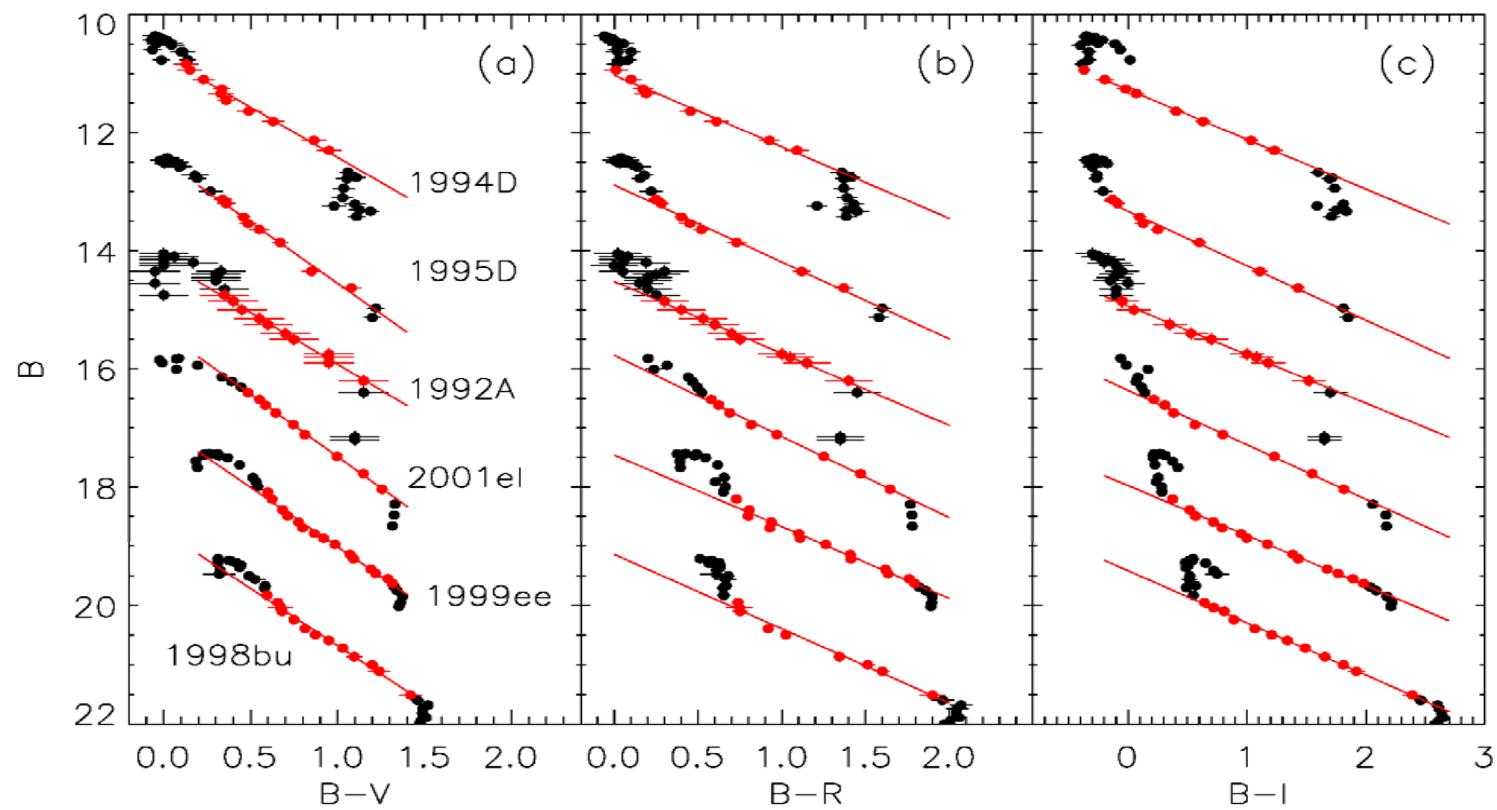
Wang, Goldhaber, Aldering, & Perlmutter (2003)

Color-Magnitude Intercept Calibration Technique for Type Ia Supernovae



Wang, Goldhaber, Aldering, & Perlmutter (2003)

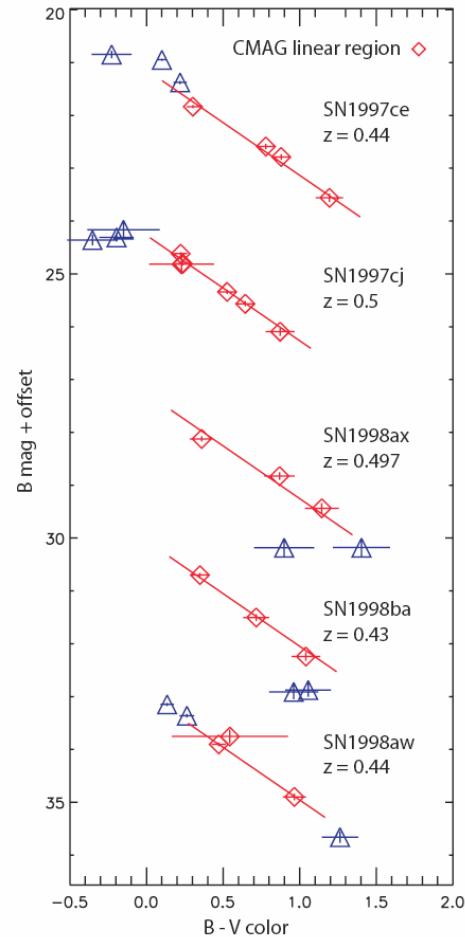
CMAGIC intrinsic dispersion & CMAGIC in other colors



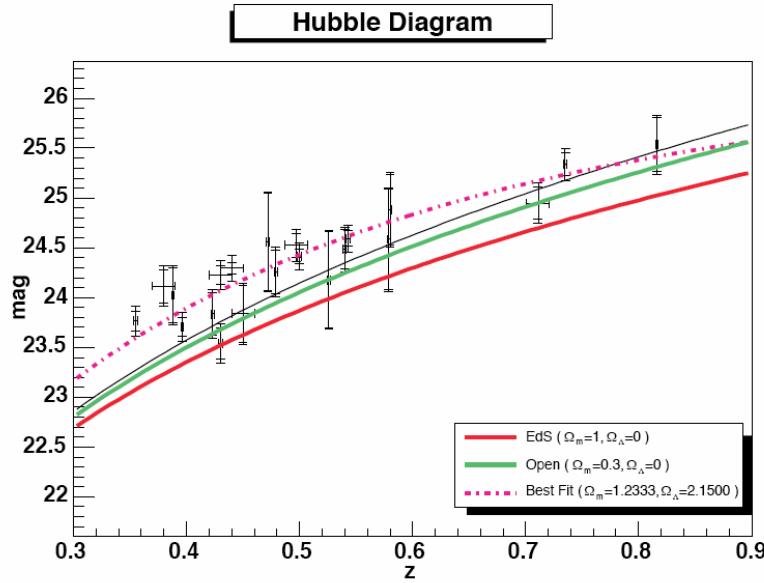
Wang, Strovink, Goldhaber, Siegrist, Perlmutter, Conley

Apply CMAGIC to high redshift SNe

- Alternative method provides systematic cross check of previous results
- SCP + literature SNe
 - 21 high z, 31 low z
- Cosmology fit done as “blind” analysis - conceal final results while developing analysis



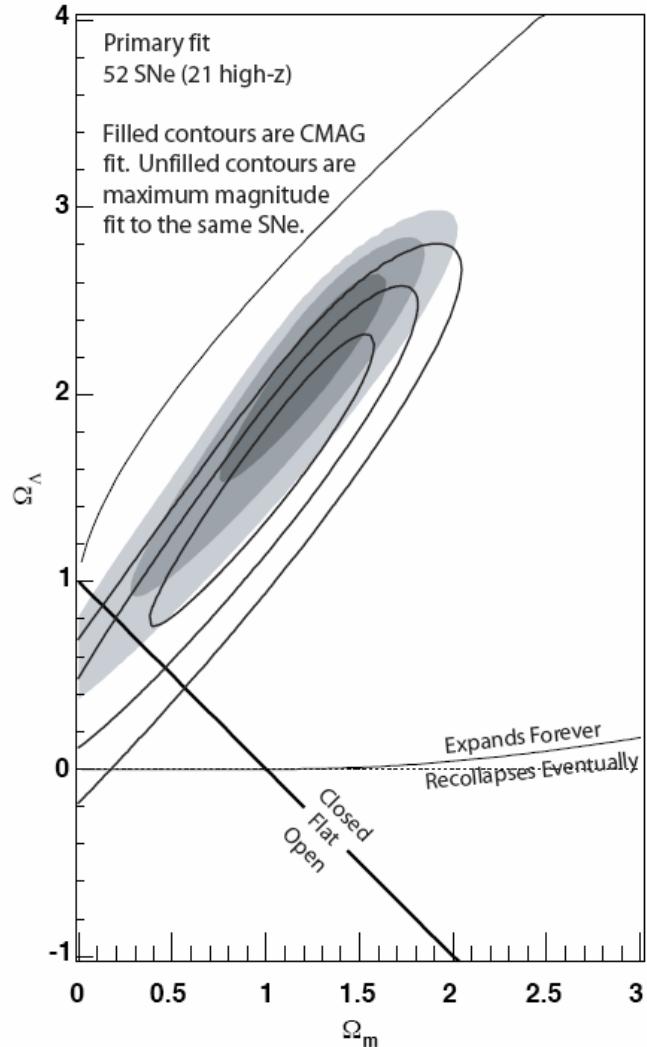
Cosmological Parameters



$$\Omega_1 = 0.790\Omega_m - 0.613\Omega_\Lambda = -0.349_{-0.131}^{+0.117} \text{ (stat)}_{-0.062}^{+0.060} \text{ (syst)}$$

$$\Omega_2 = 0.613\Omega_m + 0.790\Omega_\Lambda = 2.502_{-0.838}^{+0.530} \text{ (stat)}_{-0.545}^{+0.476} \text{ (syst)}$$

$$\Omega_m = 0.191_{-0.057}^{+0.059} \text{ (stat)}_{-0.049}^{+0.029} \text{ (syst)}$$



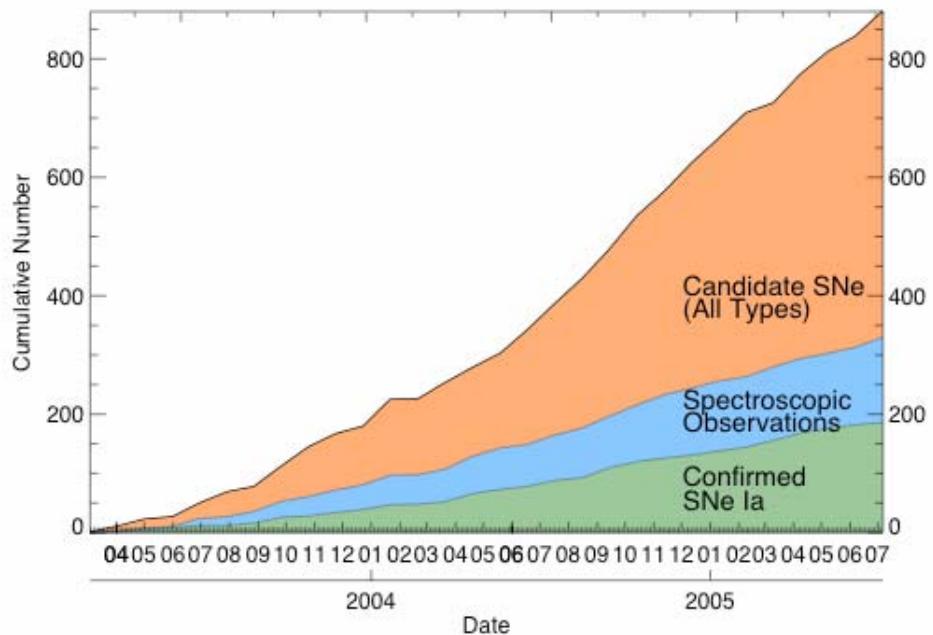
A. Conley, PhD thesis. March 2005
ApJ submitted

	Strategy:	Analyzing:	Running:	Planning:
$z = 0.02$ Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	Nearby SN factory commissioning collecting data	SN factory upgrades?
$z = 0.1$ Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	SCP+Literature data: "Blinded" <i>CMAGIC</i>	SN Legacy Survey: first results	<p>Dark Energy Survey</p> <p>SNAP</p>
$z = 0.9$ Very-High- z	<p>First probes of decelerating redshift range.</p> <p>Look for basic trends and any "danger signs" before SNAP</p>	<p>"Albinoni": first decelerating SN</p> <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	HST search: highest- z discoveries	<p>HST search 2?</p> <p>SNAP</p>
$z = 1.7$				

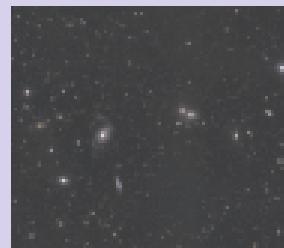
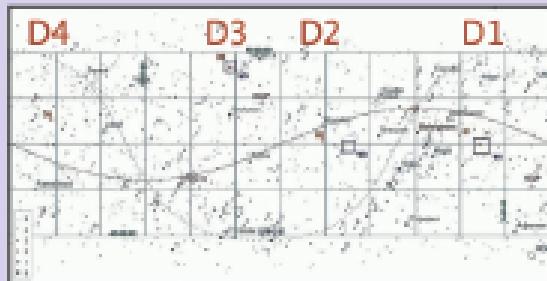
Strategy:		Analyzing:	Running:	Planning:
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$z = 1.7$				

SuperNova Legacy Survey at CFHT

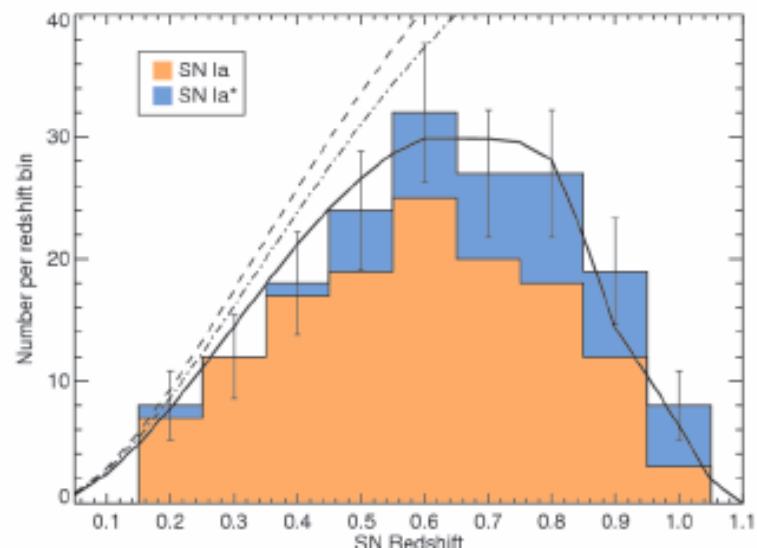
- Started March '03.
- 40 (d) nights/year for 5 years
- 4 square degrees : u', g', r', i', z'
- g',r',i',z' every 2-3 nights for 10 months/y
- 15', 30', 1h, 30'
- Detection up to $z = 1.2 - 1.3$
- Multicolor LC follow- up up to $z=0.9$
- 2000 SN Ia + 2000 SN II ? + AGNs ? + .
- 600 well measured SNIa $0.3 < z < 0.9$



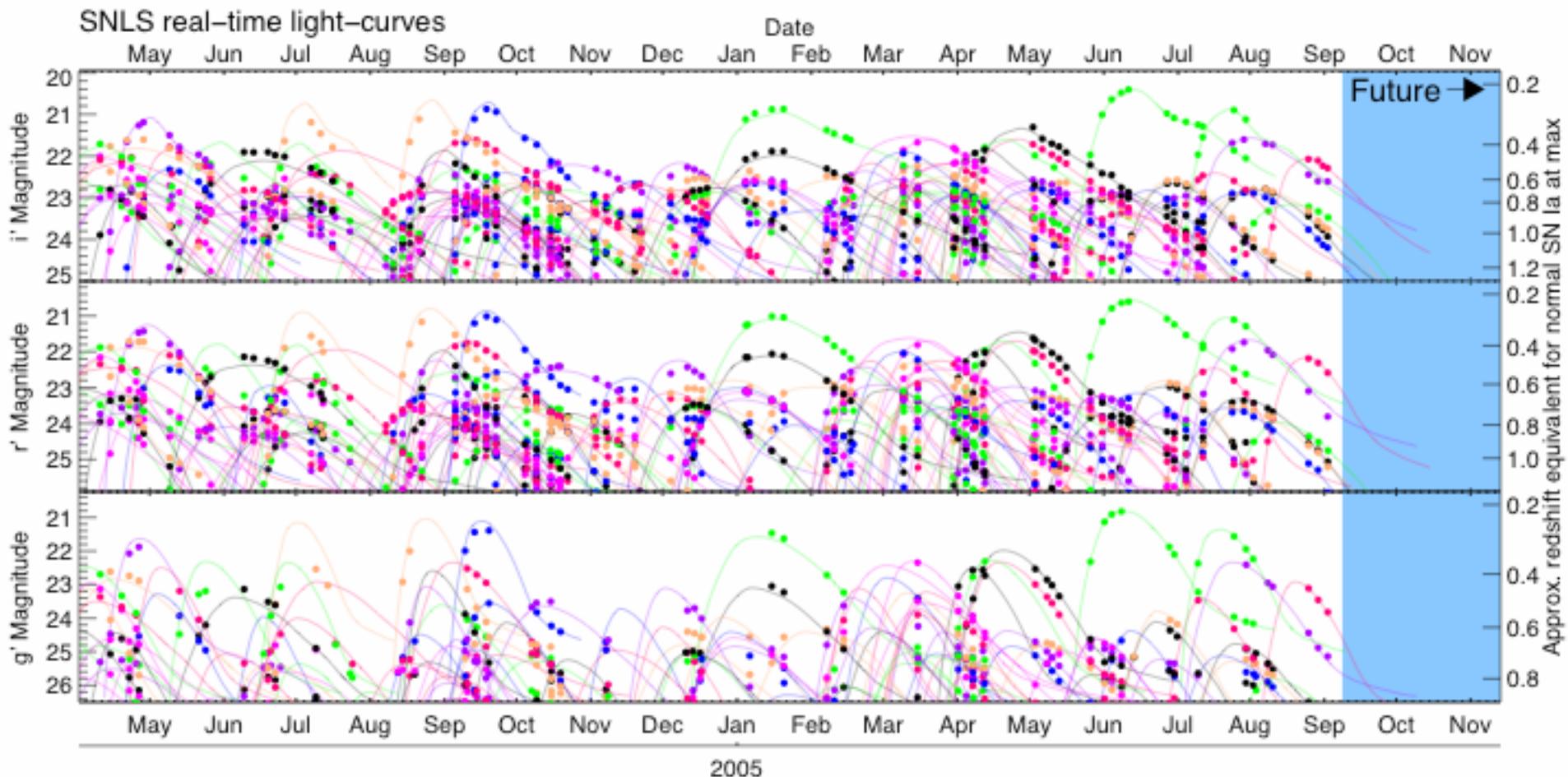
Four Megacam 1° "Deep Fields" ...



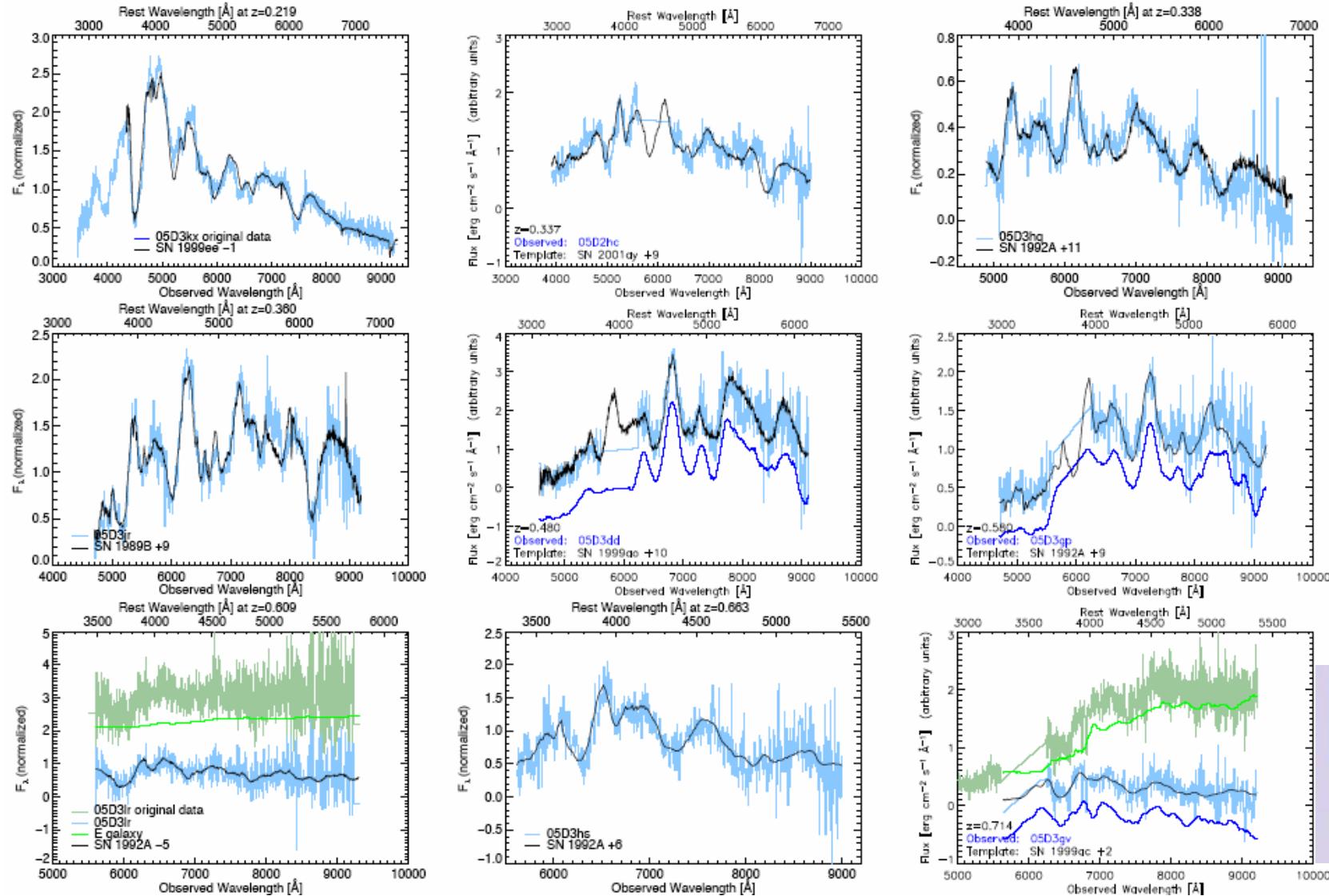
A small portion of D2.



SuperNova Legacy Survey at CFHT



SNe Ia Spectra from Keck



Data
from
LBL
group:
Kowalski
Schlegel
Perlmutter
Aldering

Spectra of some of the SNLS SN candidates obtained during the 2005A Keck LRIS observing campaign. The light-blue lines show the data after host galaxy subtraction (if necessary), rebinned to 10Å. Overplotted in black are the best fit SN templates. The spectra are confirmed by Keck to be Type Ia SNe.

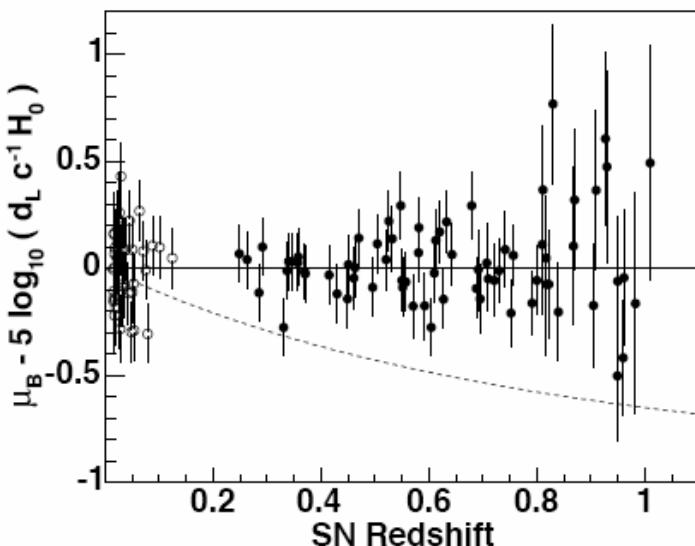
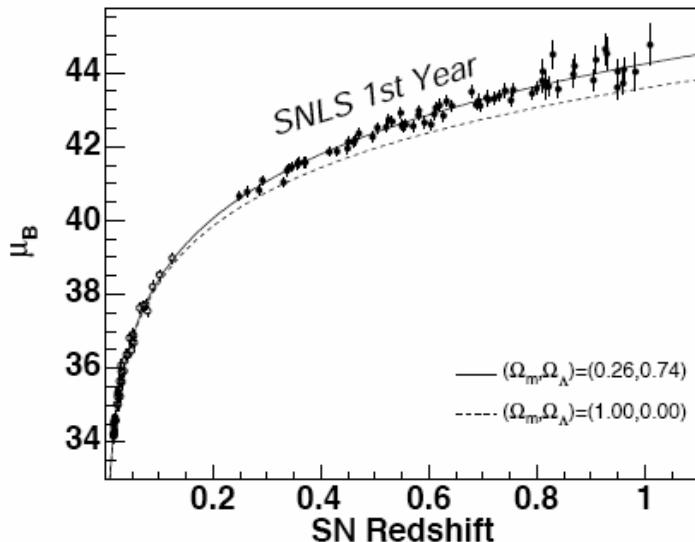
First-year results from SNLS

**The Supernova Legacy Survey:
Measurement of Ω_M , Ω_Λ and w from
the First Year Data Set**

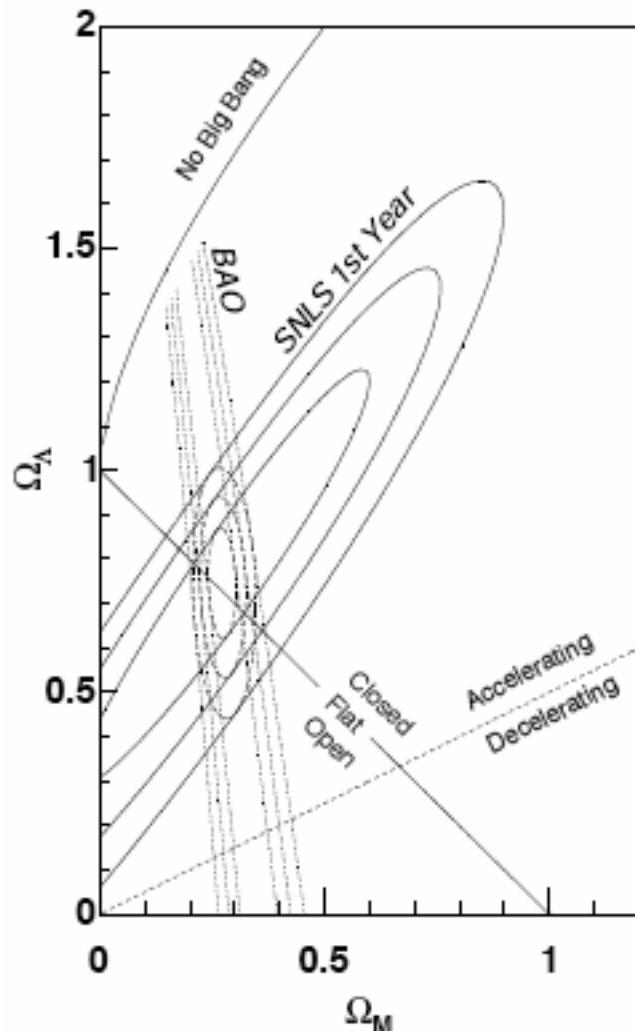
P. Astier, et al., astro-ph/0510447

71 high redshift type Ia
supernovae

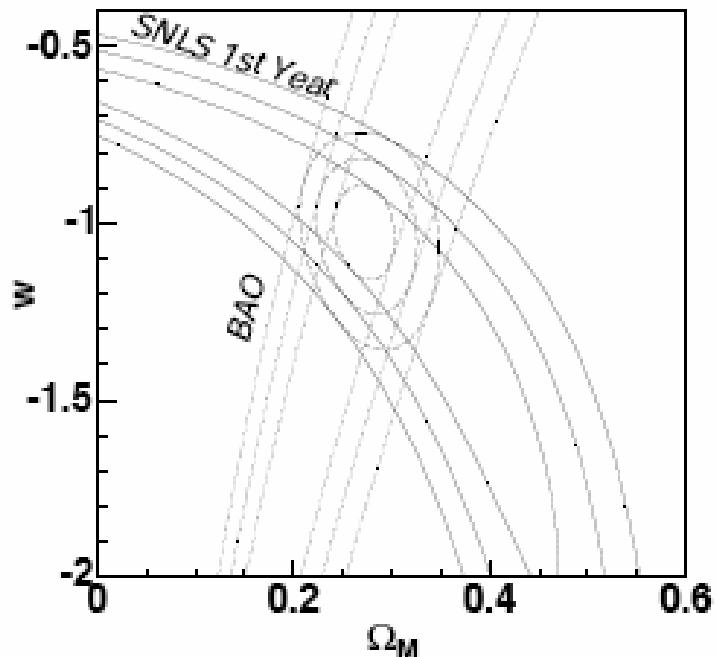
Hubble diagram of SNLS and nearby SNe Ia, with various cosmologies superimposed. The bottom plot shows the residuals for the best fit to a flat Λ -cosmology.



First-year results from SNLS



Contours at 68.3%, 95.5% and 99.7% confidence levels for the fit to an $(\Omega_M, \Omega_\Lambda)$ cosmology from the SNLS Hubble diagram(solid contours), the SDSS baryon acoustic oscillations(Eisenstein et al. 2005, dotted lines), and the joint confidence contours (dashed lines).

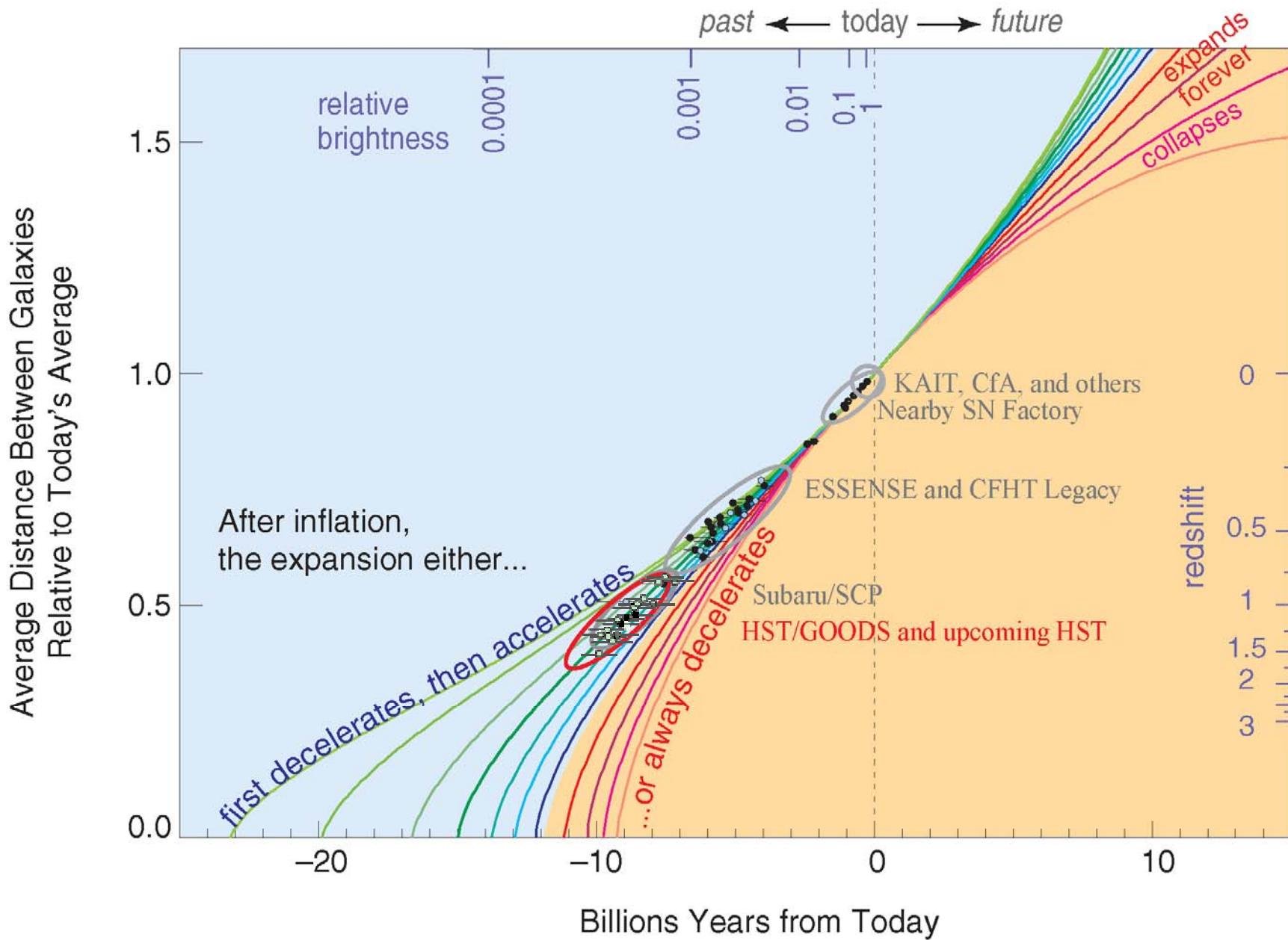


Contours at 68.3%, 95.5% and 99.7% confidence levels for the fit to a flat (Ω_M, w) cosmology, from the SNLS Hubble diagram alone, from the SDSS baryon acoustic oscillations alone (Eisenstein et al. 2005), and the joint confidence contours.

Strategy:		Analyzing:	Running:	Planning:
$z = 0.02$	Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	<p>Nearby SN factory commissioning collecting data</p>
$z = 0.1$	Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	<p>SCP+Literature data: "Blinded" <i>CMAGIC</i></p>	<p>Dark Energy Survey</p> <p>SNAP</p>
$z = 0.9$	Very-High- z	<p>First probes of decelerating redshift range.</p> <p>Look for basic trends and any "danger signs" before SNAP</p>	<p>"Albinoni": first decelerating SN</p> <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	<p>HST search 2?</p> <p>SNAP</p>
$z = 1.7$				

Strategy:		Analyzing:	Running:	Planning:
$z = 0.02$	Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	<p>Nearby SN factory commissioning collecting data</p>
$z = 0.1$	Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	<p>SCP+Literature data: "Blinded" <i>CMAGIC</i></p>	<p>Dark Energy Survey</p> <p>SNAP</p>
$z = 0.9$	Very-High- z	<p>First probes of decelerating redshift range.</p> <p>Look for basic trends and any "danger signs" before SNAP</p>	<p>"Albinoni": first decelerating SN</p> <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	<p>HST search 2?</p> <p>SNAP</p>
$z = 1.7$			<p>HST search: highest-z discoveries</p>	

Expansion History of the Universe



SN



Dust



Lensing



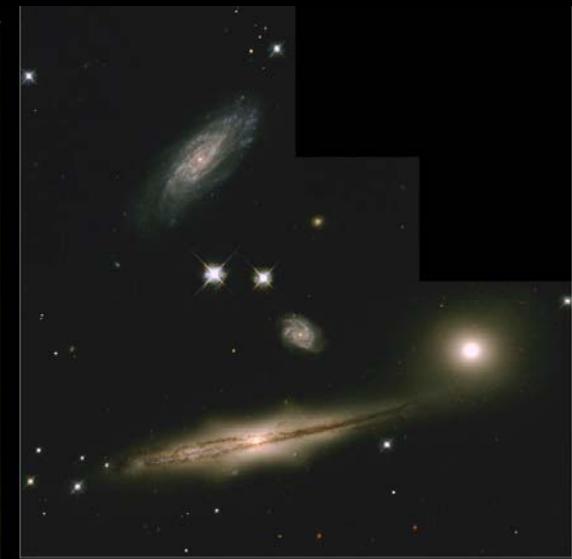
Optical
Atmosphere



Filters



Edge-On Galaxy
NGC 4013



Hickson Compact
Group 87



Dust

Lensing

Optical
Atmosphere

Filters

Optical
IR
Detectors

Interpretation

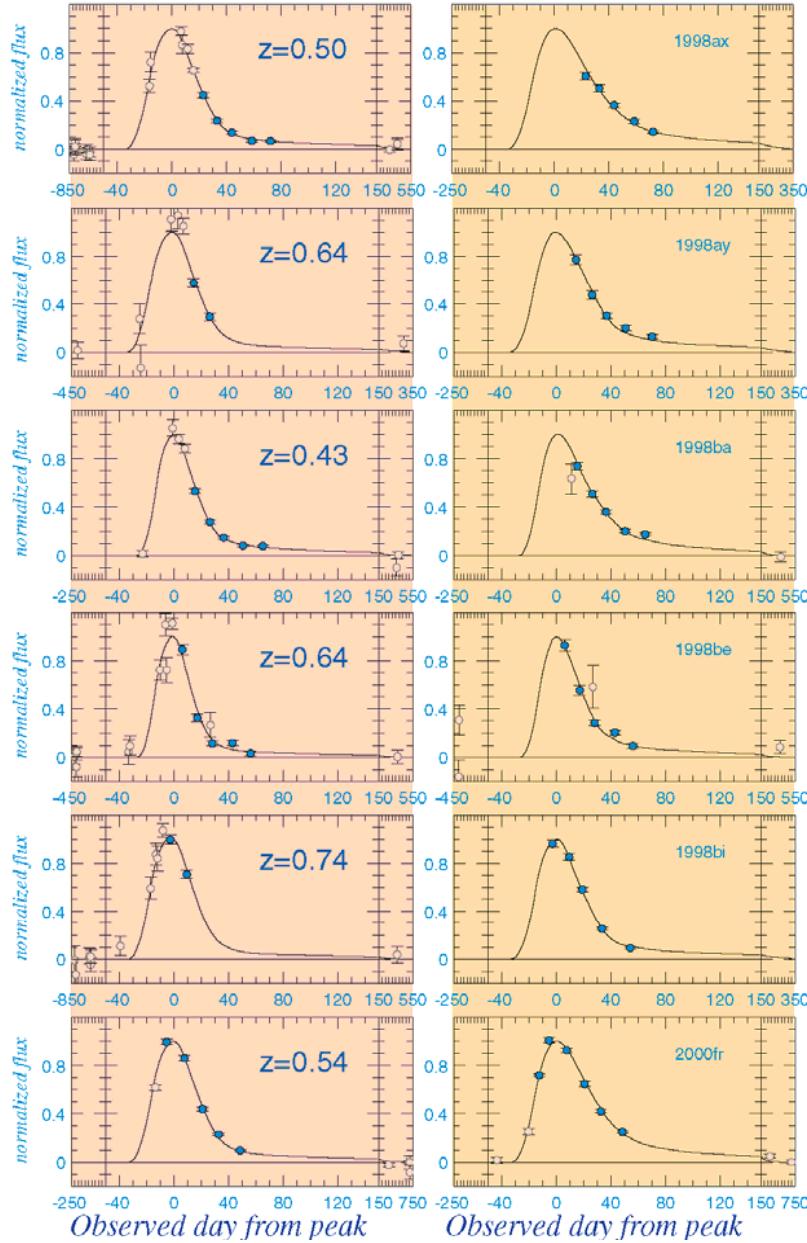
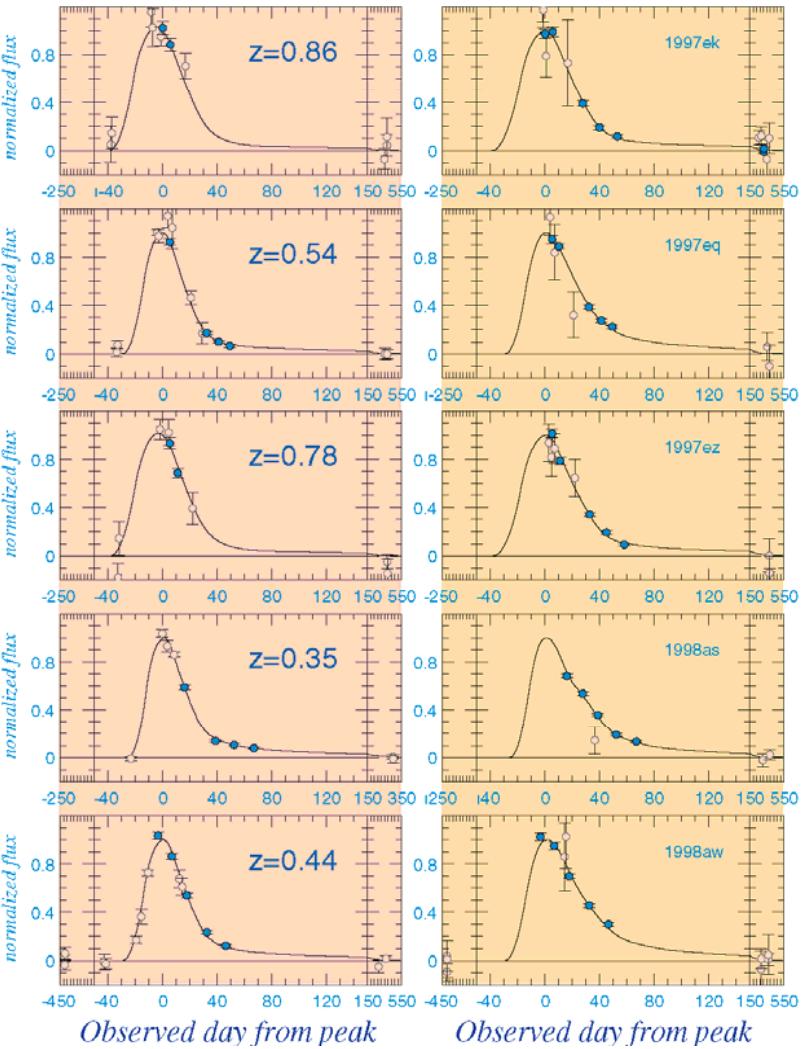
Knop et al (ApJ, 2003)

Supernova Cosmology Project

- HST observations
- Ground-based obs.

R

I

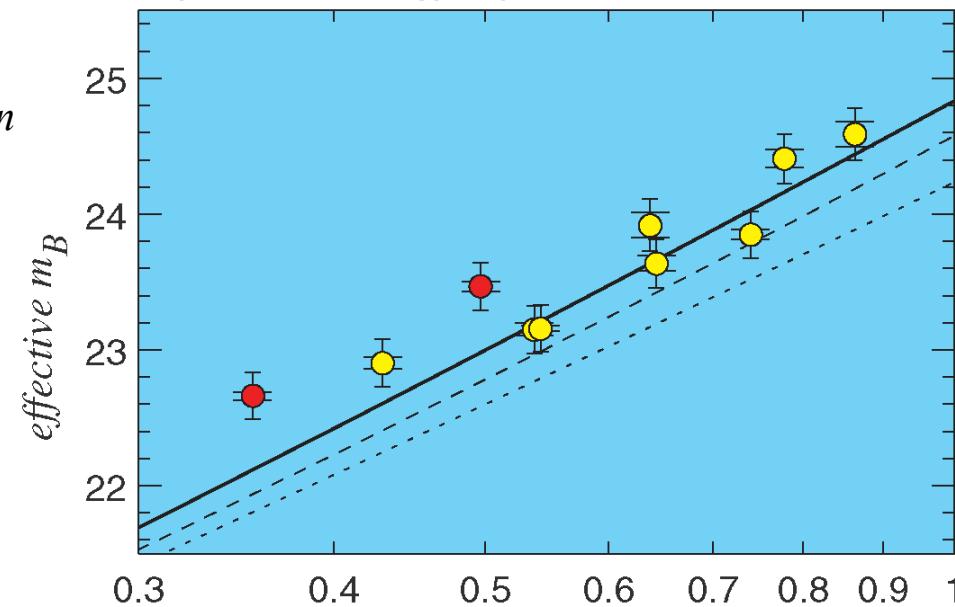




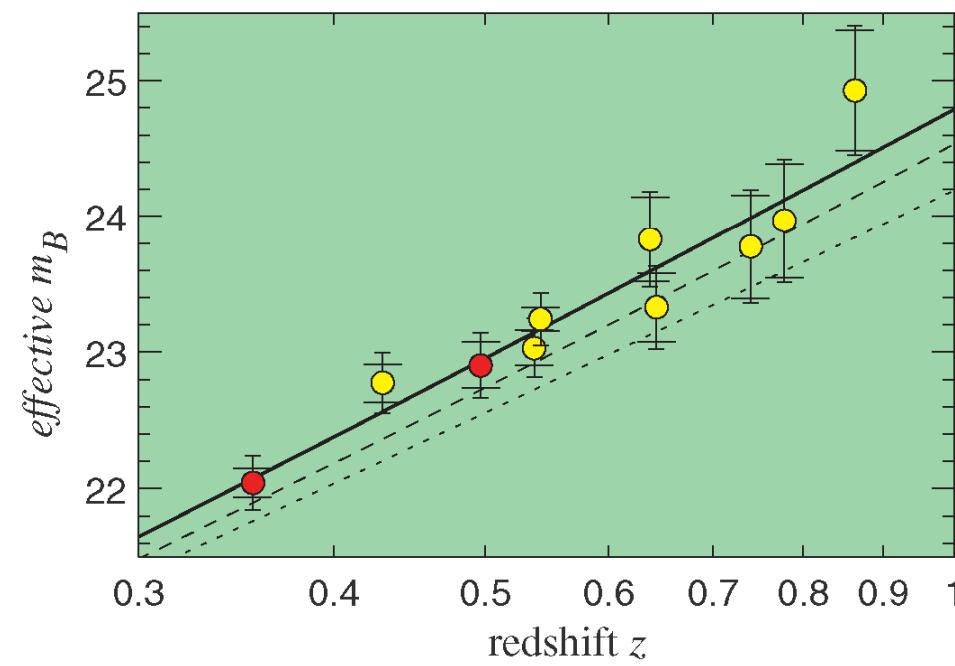
Knop et al. (ApJ, 2003)
Supernova Cosmology Project

$(\Omega_M, \Omega_\Lambda) =$
(0.3, 0.7)
(0.3, 0.0)
(1.0, 0.0)

*Before Extinction
Correction*



*After Extinction
Correction*





Dust
Lensing

Optical
Atmosphere

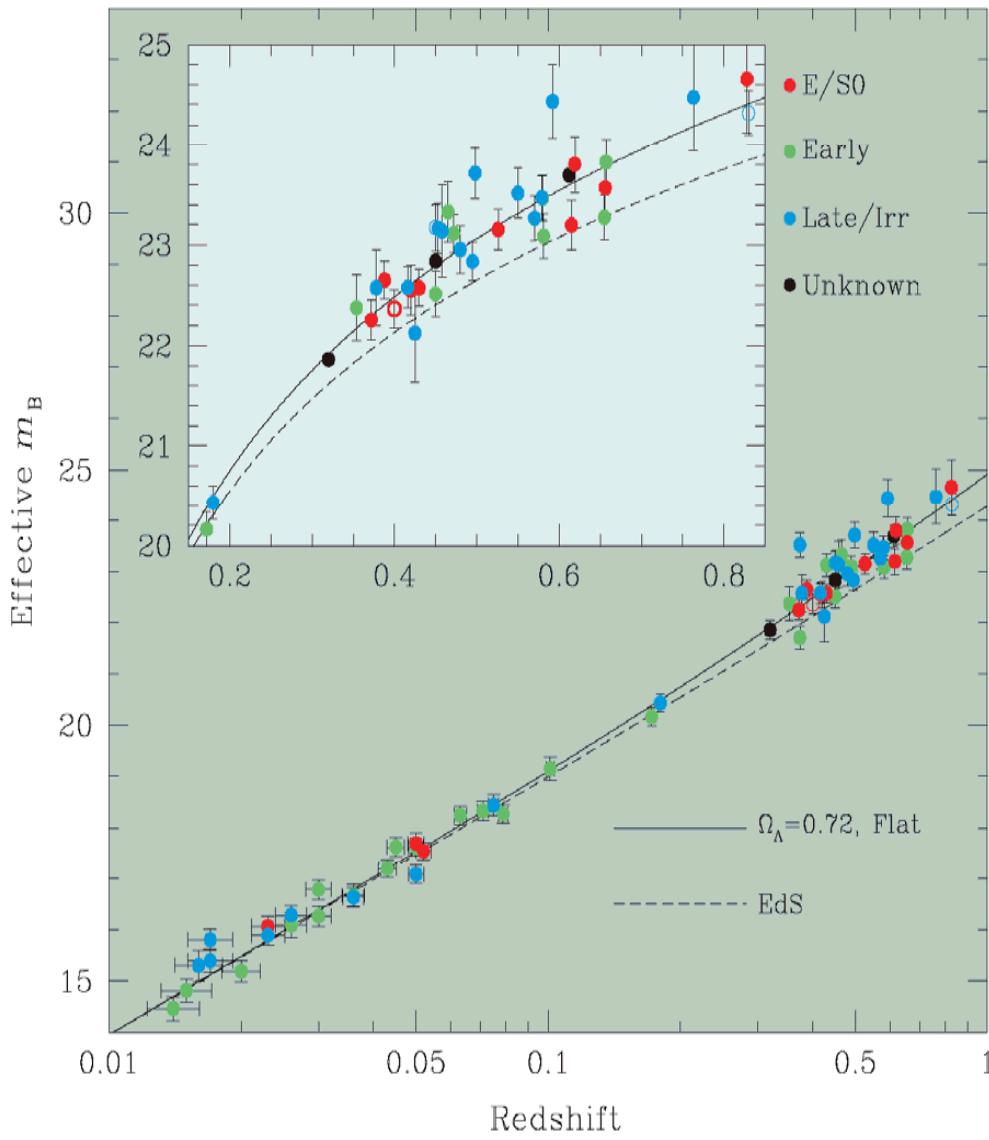


Filters
Optical
Detectors



Interpretation

Sullivan, et al. (2003) Supernova Cosmology Project



galaxy type	dispersion from best fit flat model
Elliptical: E/S0	$\sigma = 0.16 \text{ mag}$
Spiral: Sa/Sb/Sc	$\sigma = 0.20 \text{ mag}$
Late/Irregular: Scd/Irr	$\sigma = 0.27 \text{ mag}$

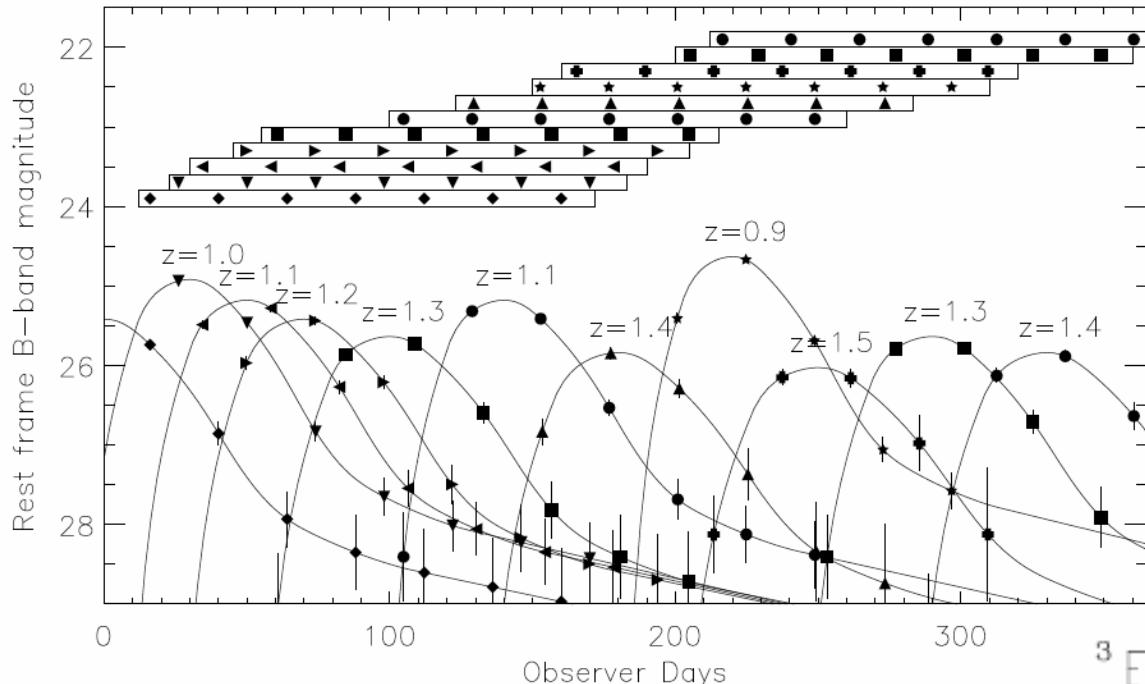
Result from elliptical host galaxy subsample agrees with flat, $\Omega_\Lambda = 0.72$ result from whole dataset.

astro-ph/0211444

Decelerating and Dustfree: Targeting SNe in Very High Redshift Galaxy Clusters

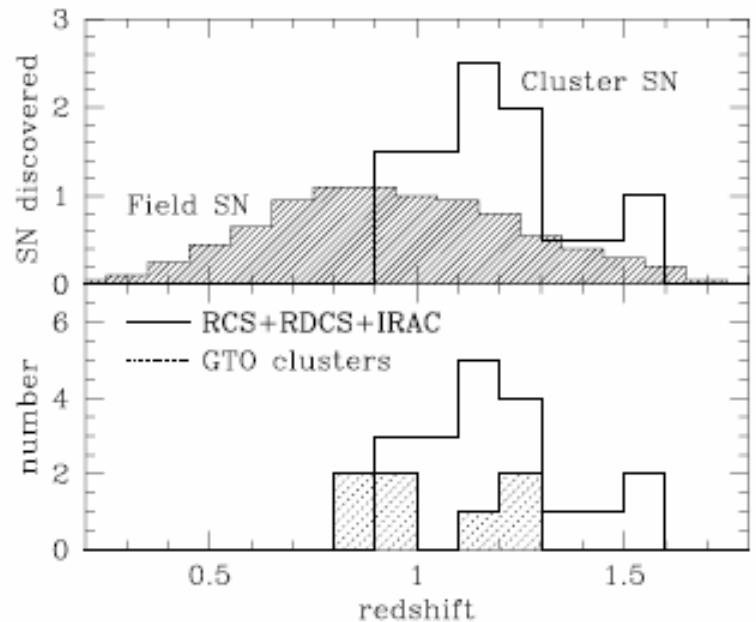
- Major 219-orbit year-long HST Program in progress in collaboration with several galaxy cluster groups
 - searching ~ 24 massive galaxy clusters at $z > 1$ with ACS
- Why clusters?
 - Dominated by nearly dust-free early type galaxies.
 - 5 times higher density of early type galaxies
 - SNe in these galaxies have negligible dust extinction
- Our Program
 - image clusters with cadence ~ 20-23 day in z' , i' bands
 - follow SNe with NICMOS (J band)
 - spectroscopy: 20 half-nights on Subaru, ~ 4 nights on Keck
- Scientific goals
 - Significantly improve SN constraints of dark energy - statistical *and* systematic uncertainties
 - Cluster studies: weak lensing, galaxy morphology, and color-magnitude relationship.

SNe in Very High Redshift Galaxy Clusters

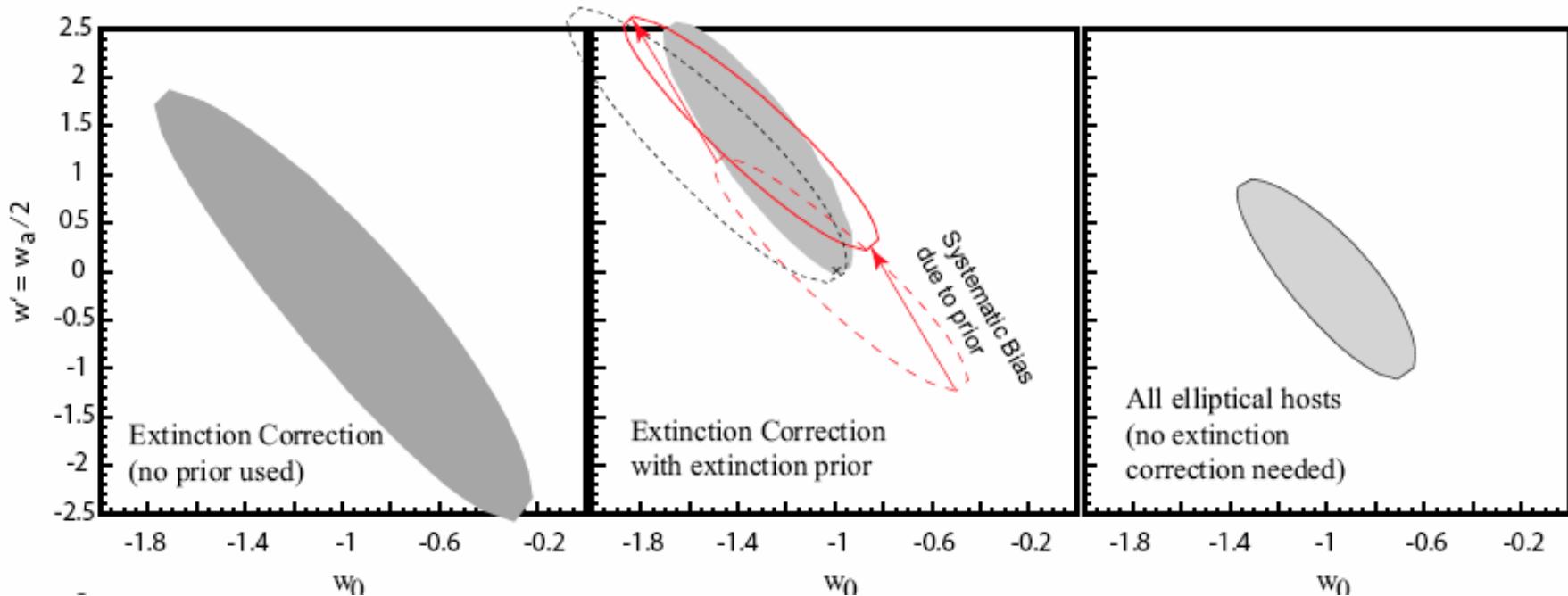


Observational program

Redshift distribution of SNe

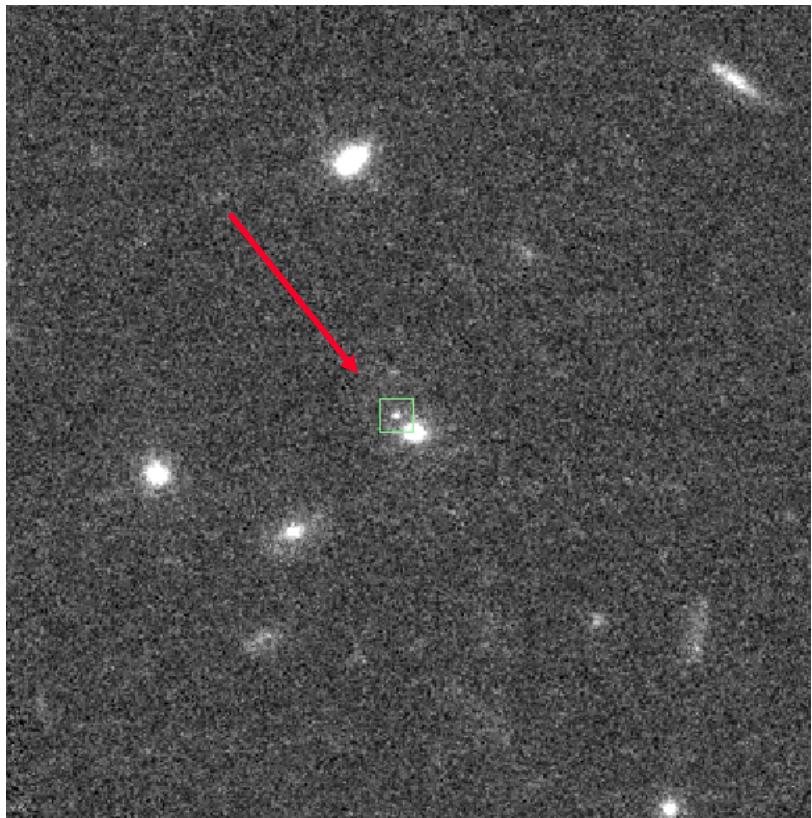


SNe in Very High Redshift Galaxy Clusters

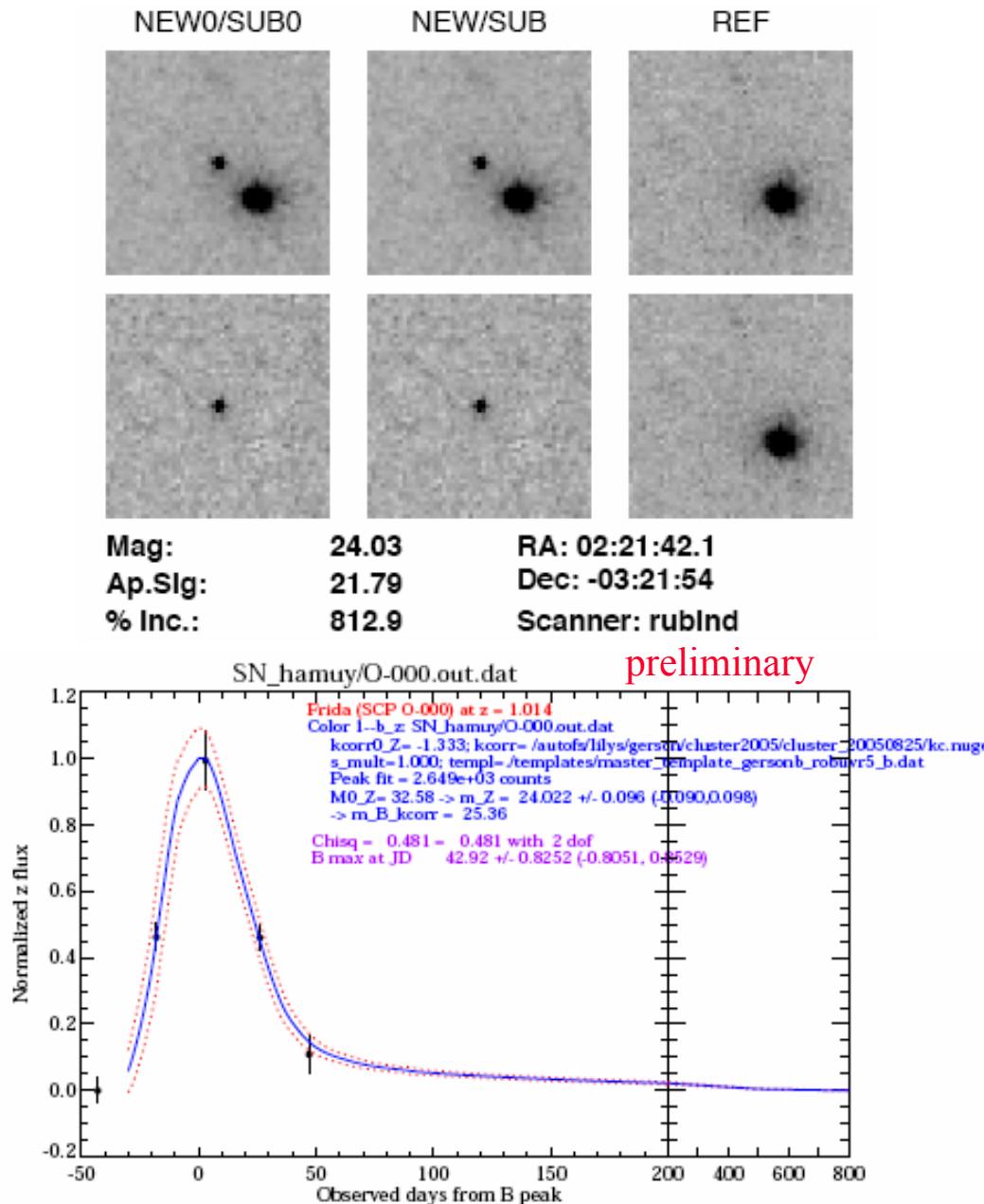


- (a) **Left Panel:** Simulated 68% confidence region on w' vs. w_0 for the current literature SN sample but with underlying cosmology($w_0 = -1$; $w' = 0$). The parameters are poorly constrained because color errors are magnified by $RB \sim 4$.
- (b) **Middle Panel:** The solid red contour shows reduced uncertainties (excluding systematic bias) using a Bayesian prior on the extinction distribution prior to suppress color errors. The filled gray contour is from Riess et al. 2004 using this prior. The short-dashed contour shows that this approach is also sensitive to shifts in RB with redshift; the example shifts from 4.1 to 2.6.
- (c) **Right Panel:** The goal of this project is shown as a confidence region for a simulated new sample of 10 $z > 1$ SNe Ia found in cluster ellipticals, together with 5 in ellipticals from the past and ongoing GOODS searches, as well as 120 SNe Ia in ellipticals at the lower redshifts now being produced by the ground-based CFHT SN Legacy Survey, the CTIO Essence survey, and (at $z < 0.1$) the Nearby SN Factory

First SN discovered in a cluster in this search



Cluster RCS0221-03
at $z = 1.02$



SNe discovered in ongoing search

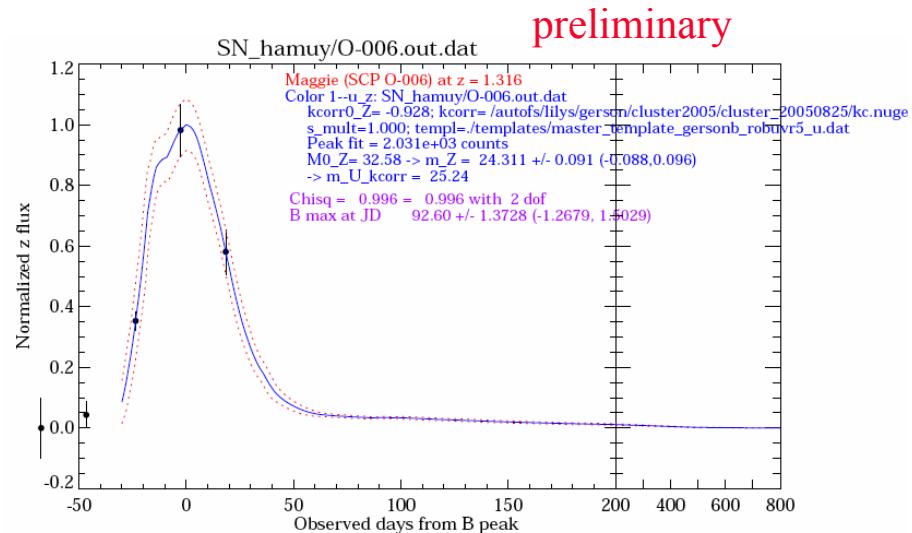
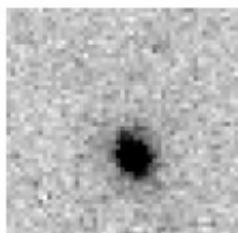
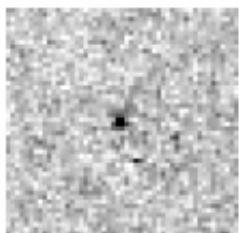
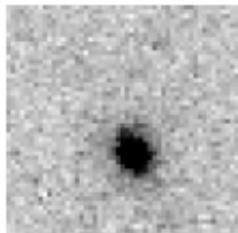
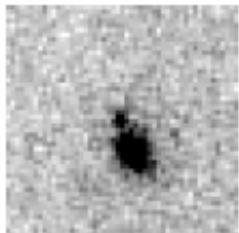
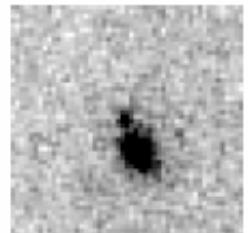
O-006

NEW0/SUB0

$z=1.316$

NEW/SUB

REF



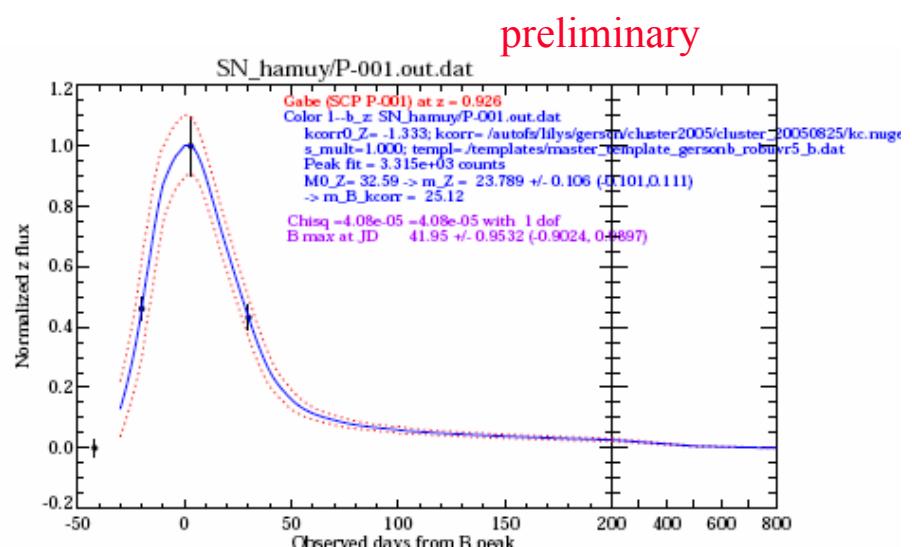
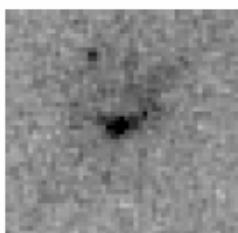
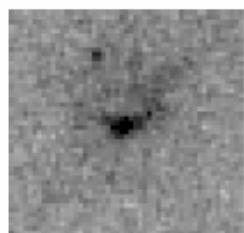
P-001

NEW0/SUB0

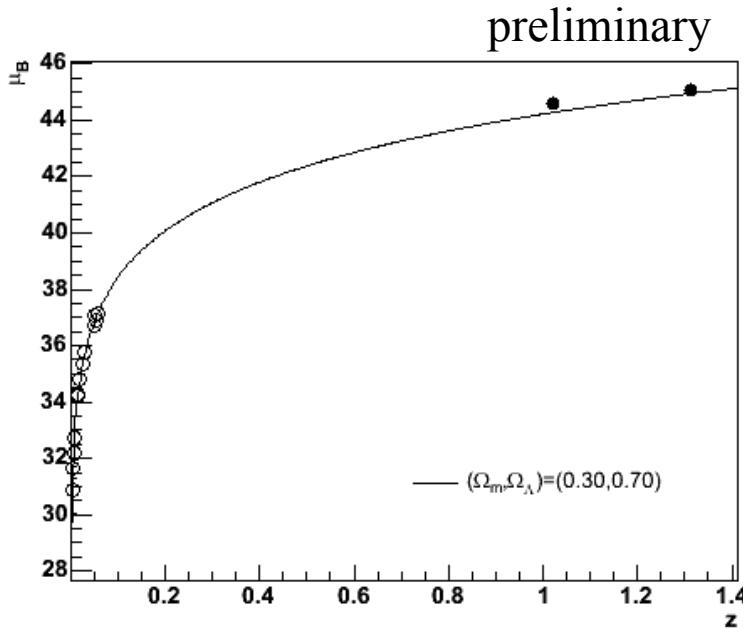
$z=0.926$

NEW/SUB

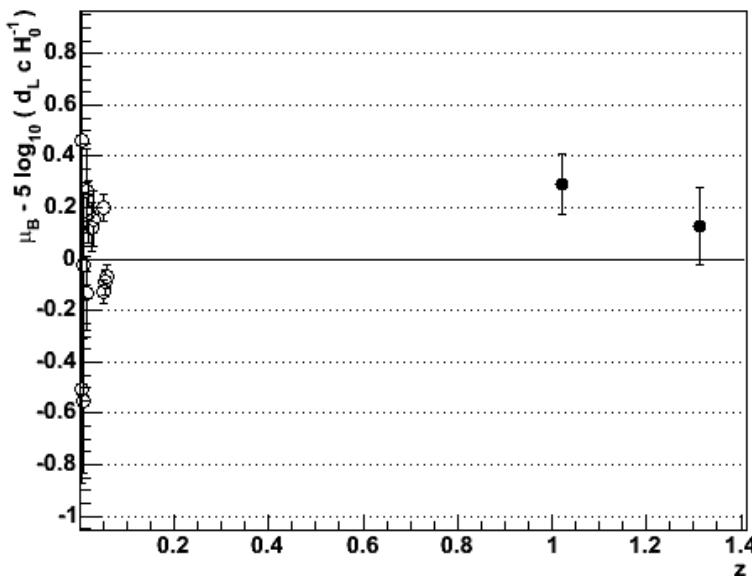
REF



Placing SNe on Hubble Diagram



These SNe are found in
elliptical galaxies - no
extinction correction



	Strategy:	Analyzing:	Running:	Planning:
$z = 0.02$ Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	Nearby SN factory commissioning collecting data	SN factory upgrades?
$z = 0.1$ Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	SCP+Literature data: "Blinded" <i>CMAGIC</i>	SN Legacy Survey: first results	<p>Dark Energy Survey</p> <p>SNAP</p>
$z = 0.9$ Very-High- z	<p>First probes of decelerating redshift range.</p> <p>Look for basic trends and any "danger signs" before SNAP</p>	<p>"Albinoni": first decelerating SN</p> <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	HST search: highest- z discoveries	<p>HST search 2?</p> <p>SNAP</p>
$z = 1.7$				

SCP Publications in past year (1)

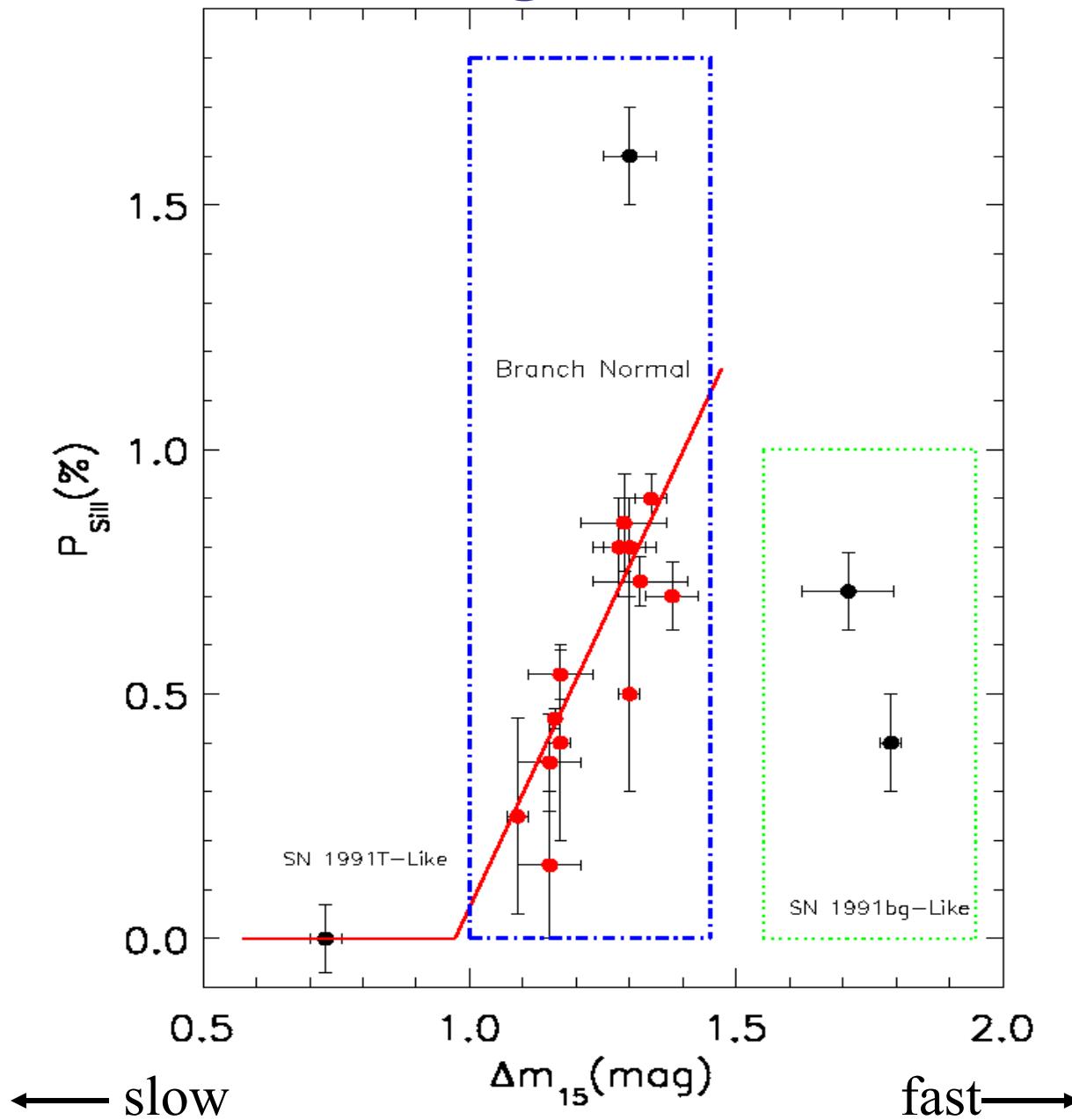
1. Spectra of High Redshift Type Ia Supernovae and a Comparison with their Low Redshift Counterparts.
 - I. Hook et al., AJ in press. astro-ph/0509041
2. Spectroscopic confirmation of high-redshift supernovae with the ESO VLT,
 - C. Lidman et al., A&A 430, 843 (2005) astro-ph/0410506
3. Spectroscopic Observations and Analysis of the Unusual Type Ia SN 1999ac,
 - G. Garavini et al., AJ in press. astro-ph/0507288
4. Restframe I-band Hubble Diagram for Type Ia Supernovae up to Redshift $z \sim 0.5$,
 - S. Nobili et al., A&A, 437, 789 (2005). Also available at astro-ph/0504139
5. Photometric selection of high-redshift type Ia supernovae,
 - M. Sullivan et al., AJ accepted, astro-ph/05010857
6. The Supernova Legacy Survey: Measurement of Ω_M , Ω_Λ and w from the First Year Data,
 - P. Astier et al., A&A accepted, astro-ph/0510447
7. Gemini Spectroscopy Of Supernovae From SNLS: Improving High Redshift SN Selection and Classification,
 - A. Howell et al, ApJ accepted, astro-ph/0509195

SCP Publications in past year (2)

8. Measurement of Ω_M , Ω_Λ from an analysis of Type Ia SNe with CMAGIC,
 - A. Conley et al., ApJ submitted.
 9. Nonlinear Decline-Rate Dependence and Intrinsic Variation of Type Ia Supernova Luminosities,
 - L. Wang, M. Strovink, A. Conley, G. Goldhaber, M. Kowalski, J. Siegrist, and S. Perlmutter, ApJ submitted
 10. Dust around type Ia supernovae,
 - L. Wang, ApJL in press. astroph/0511003
 11. Spectropolarimetry Diagnostics of Thermonuclear SNe,
 - L. Wang, D. Baade, F. Patat, Science submitted.
-
- Estimation of the Cosmological Parameters from an Analysis of Type Ia Supernovae with CMAGIC,
 - A. Conley, PhD thesis UC Berkeley

Polarization versus lightcurve timescale

Wang, et al.
submitted

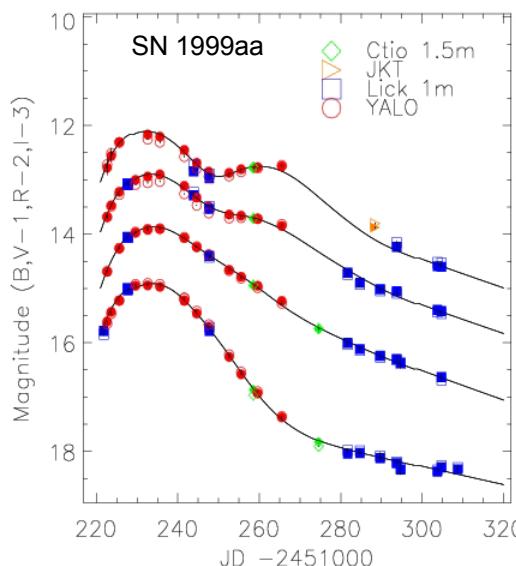
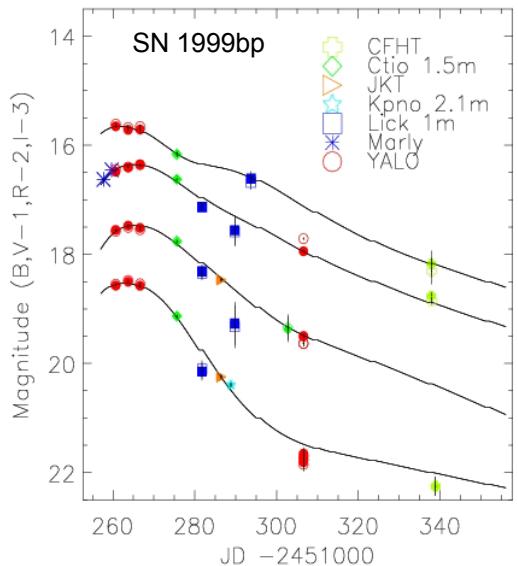
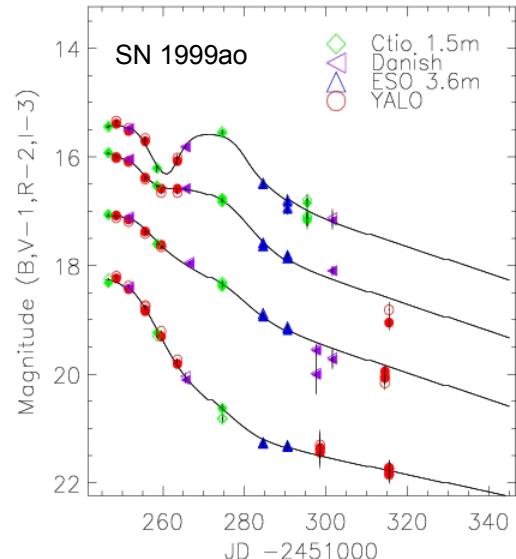
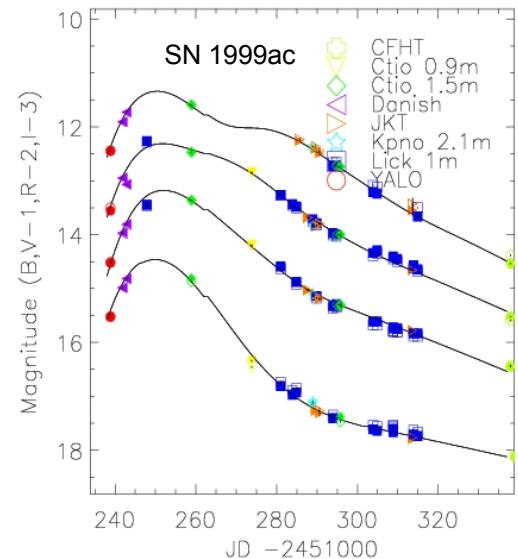
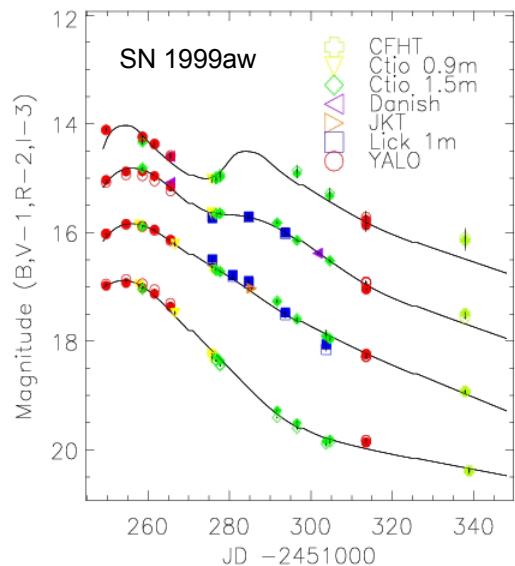


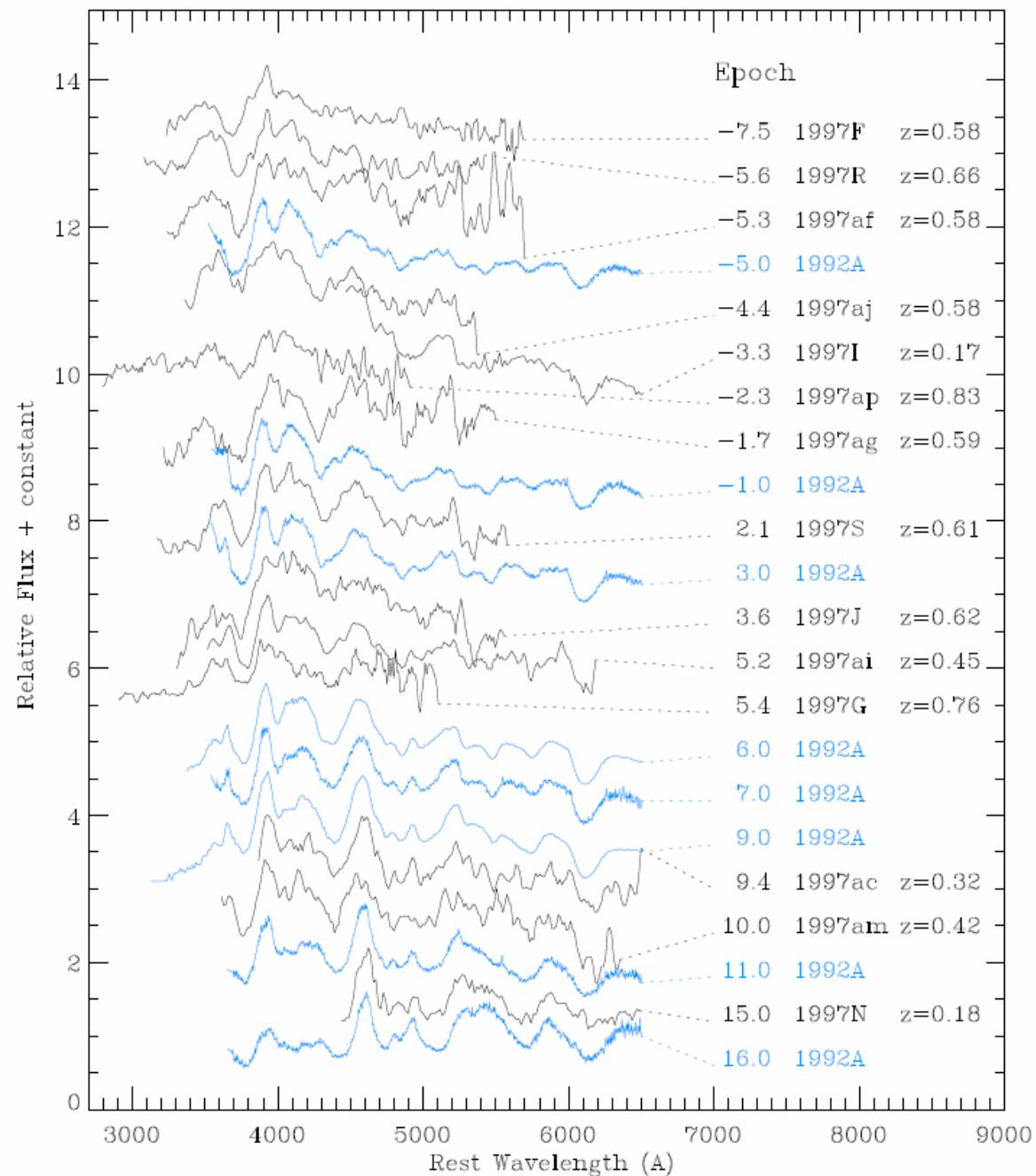
SCP 1999 Low-z SN campaign

Lightcurves - Cross calibration of multiple telescopes

- 20 nearby SN observed ($0.02 < z < 0.24$)
- ~2600 images in UBVRI
- 17 different instruments

M. Kowalski, B. Farris





Spectra of High Redshift Type Ia Supernovae and a Comparison with their Low Redshift Counterparts

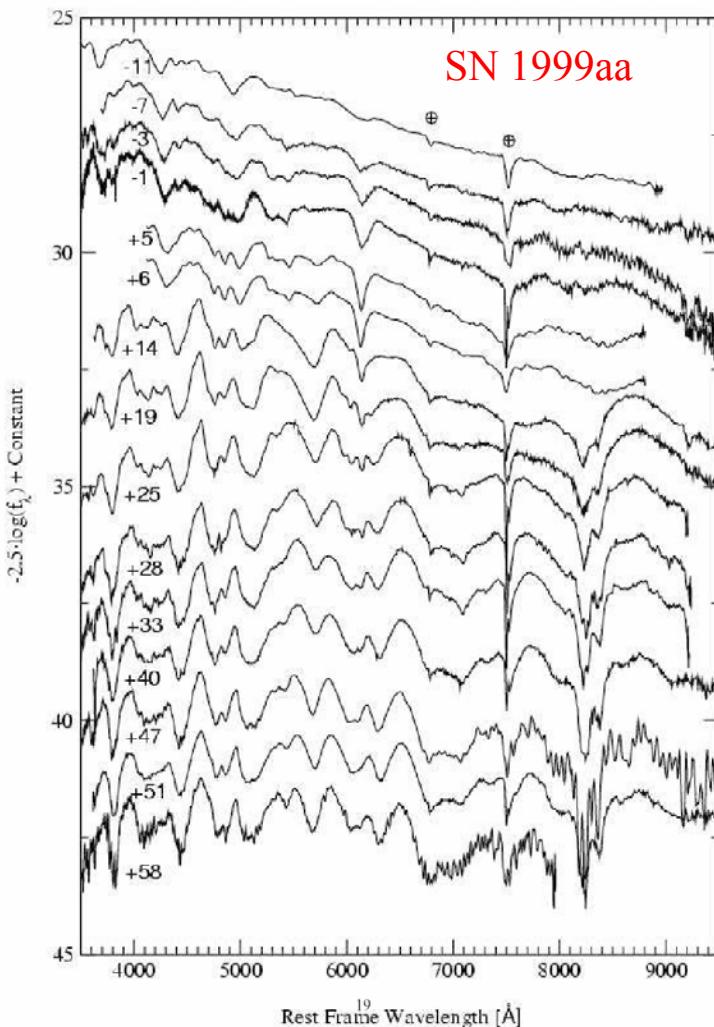
I. Hook et al., AJ in press, astro-ph/0509041

The time sequence of high redshift SN spectra in order of rest-frame date relative to maximum light as determined from the light curve. Spectra of the nearby Type Ia, SN 1992A are interspersed for comparison.

We find **no evidence for evolution** in SN Ia properties between low and high redshift samples.

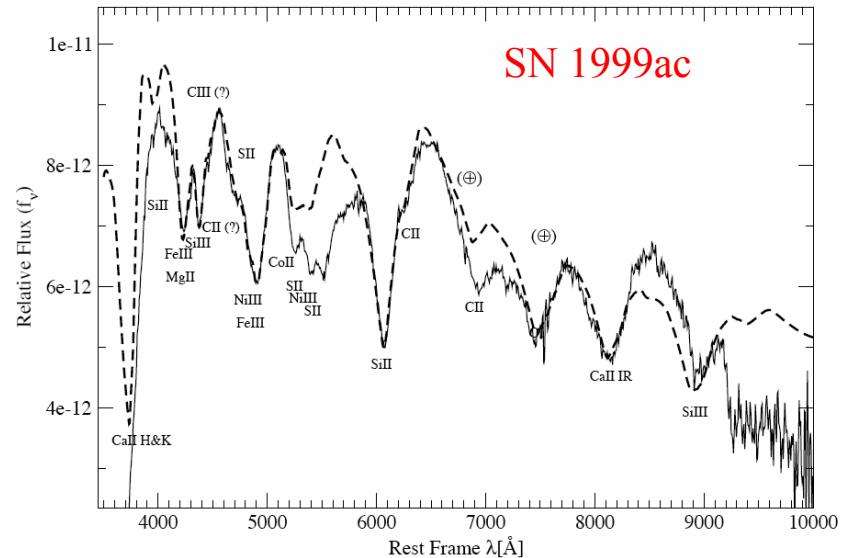
Detailed spectroscopic studies of 2 SNe

- Spectroscopic Observations and Analysis of the Peculiar SN 1999aa,
 - G. Garavini et al., AJ 128, 387



- Spectroscopic Observations and Analysis of the Unusual Type Ia SN 1999ac,
 - G. Garavini et al., AJ in press. astro-ph/0507288

High S/N spectra allow for identification and temporal evolution of intermediate mass elements



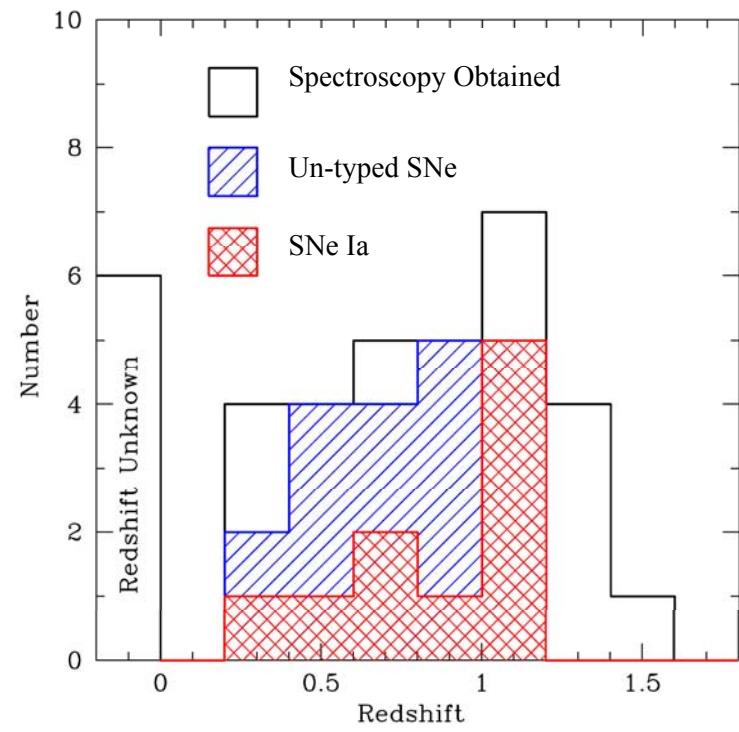
Synthetic spectrum (SYNOW)
compared with SN 1999ac
spectrum for day -15

SCP SN studies using Subaru 8.2m

- Intensive SN search with Subaru/ Suprime-Cam in 2002
 - 5 nights in Spring/11 nights in Fall
 - coordinated spectroscopy with Keck, Gemini, and VLT
- Widest field imaging camera on an 8-10m class telescope
 - FOV of 33 x 26 arcmin.

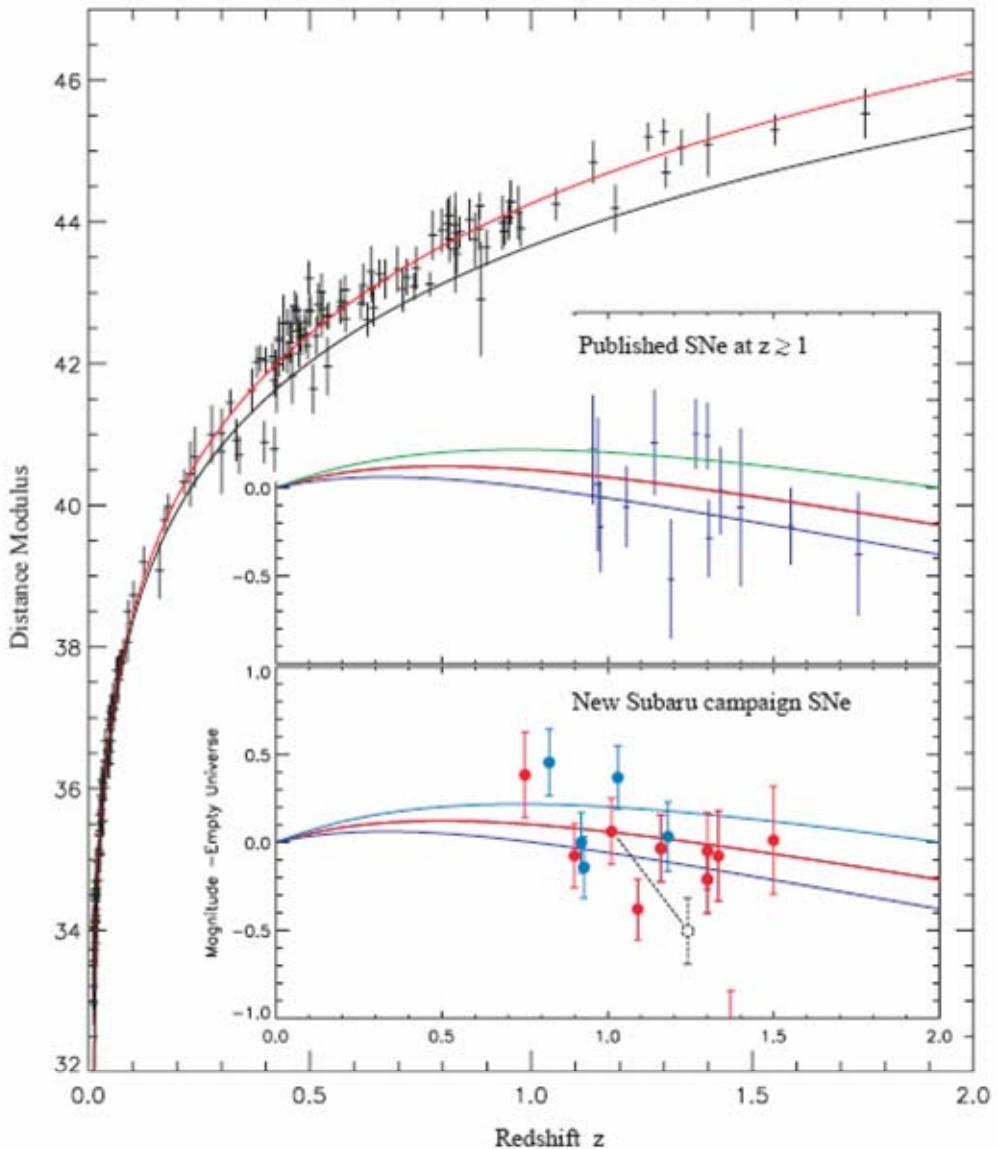
	Candi-dates	Spectrum	SNe	Spec. Confirmed SNe Ia	HST
Spring 01	22	8	7	3	1
Spring 02	55	13	7	5	4
Fall 02	44	22	25	5	3
Total	121	48	39	13	8

S. Perlmutter, G. Goldhaber, K. Dawson, V. Fadeyev,
D. Schlegel, A. Spadafora, Tokyo group



Adding SNe to Hubble diagram at the highest redshifts

SCP Subaru data will provide a significant SN sample at $z > 1$.



Dark Energy Survey Overview

- DES Science Goals: Study dark energy with four techniques
 - **Galaxy cluster surveys (with SPT)**
 - **Weak lensing**
 - **Galaxy angular power spectrum**
 - **SN Ia distances**
- Instrument and schedule
 - **New 3 deg² camera on the Blanco 4m on Cerro Tololo**
 - **Construction: 2004-2009**
 - **Survey Operations: 2009-2013**
 - **“Precursor” to SNAP, LSST**
- Two linked, multiband surveys
 - **5000 deg² g’, r’, i’ and z’**
 - **Repeated observations of 40 deg²**
 - **Catalogs made available to community after one year**

Blanco 4m Telescope on Cerro Tololo

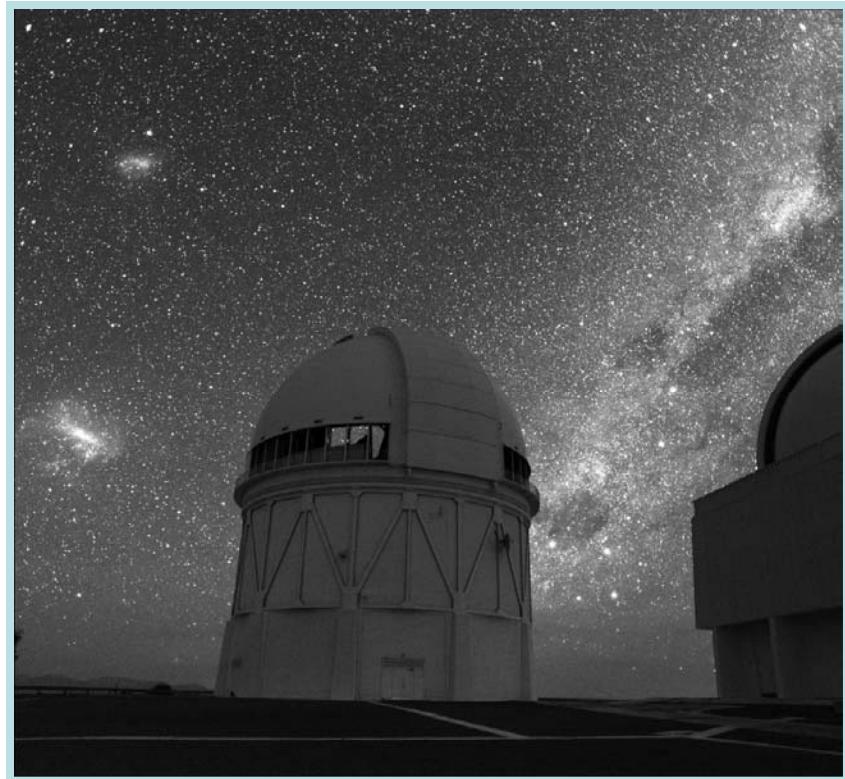


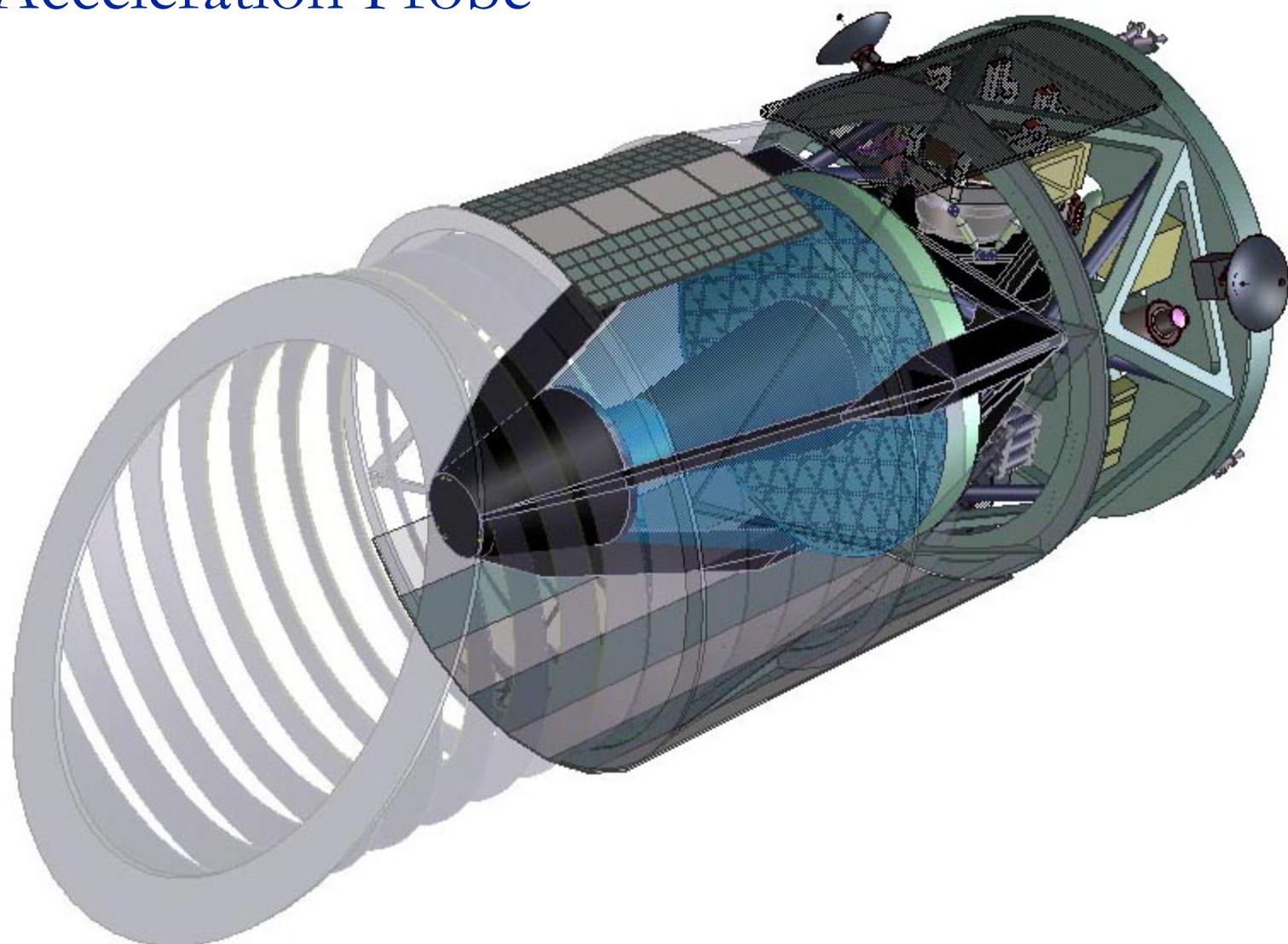
Image credit: Roger Smith/NOAO/AURA/NSF

Strategy:		Analyzing:	Running:	Planning:
$z = 0.02$	Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	<p>Nearby SN factory commissioning collecting data</p>
$z = 0.1$	Mid-High- z	<p>Build a statistical sample that can be</p> <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	<p>SCP+Literature data: "Blinded" <i>CMAGIC</i></p>	<p>Dark Energy Survey</p> <p>SNAP</p>
$z = 0.9$	Very-High- z	<p>First probes of decelerating redshift range.</p> <p>Look for basic trends and any "danger signs" before SNAP</p>	<p>"Albinoni": first decelerating SN</p> <p>A complete data set: CFHT/CTIO --> HST Subaru --> HST</p>	<p>HST search 2?</p> <p>SNAP</p>
$z = 1.7$			<p>HST search: highest-z discoveries</p>	

Strategy:		Analyzing:	Running:	Planning:
$z = 0.02$	Low- z	<p>Statistics: Need more at base of hubble diagram.</p> <p>Systematics: "Tune" and categorize the SNe Ia.</p>	<p>SCP Spring 99 data set: Spectroscopy papers Lightcurves</p> <p>Literature data: <i>CMAGIC</i></p>	Nearby SN factory commissioning collecting data
$z = 0.1$	Mid-High- z	Build a statistical sample that can be <ul style="list-style-type: none"> -- divided into systematics subsamples -- high enough quality for color correction of dust 	SCP+Literature data: "Blinded" <i>CMAGIC</i>	Dark Energy Survey SNAP
$z = 0.9$	Very-High- z	First probes of decelerating redshift range. Look for basic trends and any "danger signs" before SNAP	"Albinoni": first decelerating SN A complete data set: CFHT/CTIO --> HST Subaru --> HST	HST search 2? SNAP
$z = 1.7$				

SNAP co-PI's: Perlmutter & Levi

“SNAP”: SuperNova Acceleration Probe



SNAP Collaboration



LBNL



Berkeley



Caltech

Fermi National
Laboratory

Indiana U.

IN2P3-Paris
-Marseille

JPL

LAM (France)

University of
Michigan

University of
Pennsylvania

University of
Stockholm

SLAC

STScI

Yale U.

G. Aldering, S. Bailey, C. Bebek, W. Carithers, T. Davis[†], K. Dawson, C. Day, R. DiGennaro, S. Deustua[†], D. Groom, M. Hoff, S. Holland, D. Huterer[†], A. Karcher, A. Kim, W. Kolbe, W. Kramer, B. Krieger, G. Kushner, N. Kuznetsova, R. Lafever, J. Lamoureux, M. Levi, S. Loken, B. McGinnis, R. Miquel, P. Nugent, H. Oluseyi[†], N. Palaio, S. Perlmutter, N. Roe, H. Shukla, A. Spadafora, H. Von Der Lippe, J-P. Walder, G. Wang

M. Bester, E. Commins, G. Goldhaber, H. Heetderks, P. Jelinsky, M. Lampton, E. Linder, D. Pankow, M. Sholl, G. Smoot, C. Vale, M. White

R. Ellis, R. Massey[†], A. Refregier[†], J. Rhodes, R. Smith, K. Taylor, A. Weinstein

J. Annis, F. DeJongh, S. Dodelson, T. Diehl, J. Frieman, D. Holz[†], L. Hui, S. Kent, P. Limon, J. Marriner, H. Lin, J. Peoples, V. Scarpine, A. Stebbins, C. Stoughton, D. Tucker, W. Wester

C. Bower, N. Mostek, J. Musser, S. Mufson

P. Astier, E. Barrelet, R. Pain, G. Smadja[†], D. Vincent
A. Bonissent, A. Ealet, D. Fouchez, A. Tilquin

D. Cole, M. Frerking, J. Rhodes, M. Seiffert

S. Basa, R. Malina, A. Mazure, E. Prieto

B. Bigelow, M. Brown, M. Campbell, D. Gerdes, W. Lorenzon, T. McKay, S. McKee, M. Schubnell, G. Tarle, A. Tomasch

G. Bernstein, L. Gladney, B. Jain, D. Rusin

R. Amanullah, L. Bergström, A. Goobar, E. Mörtsell

W. Althouse, R. Blandford, W. Craig, S. Kahn, M. Huffer, P. Marshall

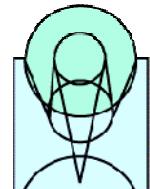
R. Bohlin, D. Figer, A. Fruchter

C. Baltay, W. Emmet, J. Snyder, A. Szymkowiak, D. Rabinowitz, N. Morgan



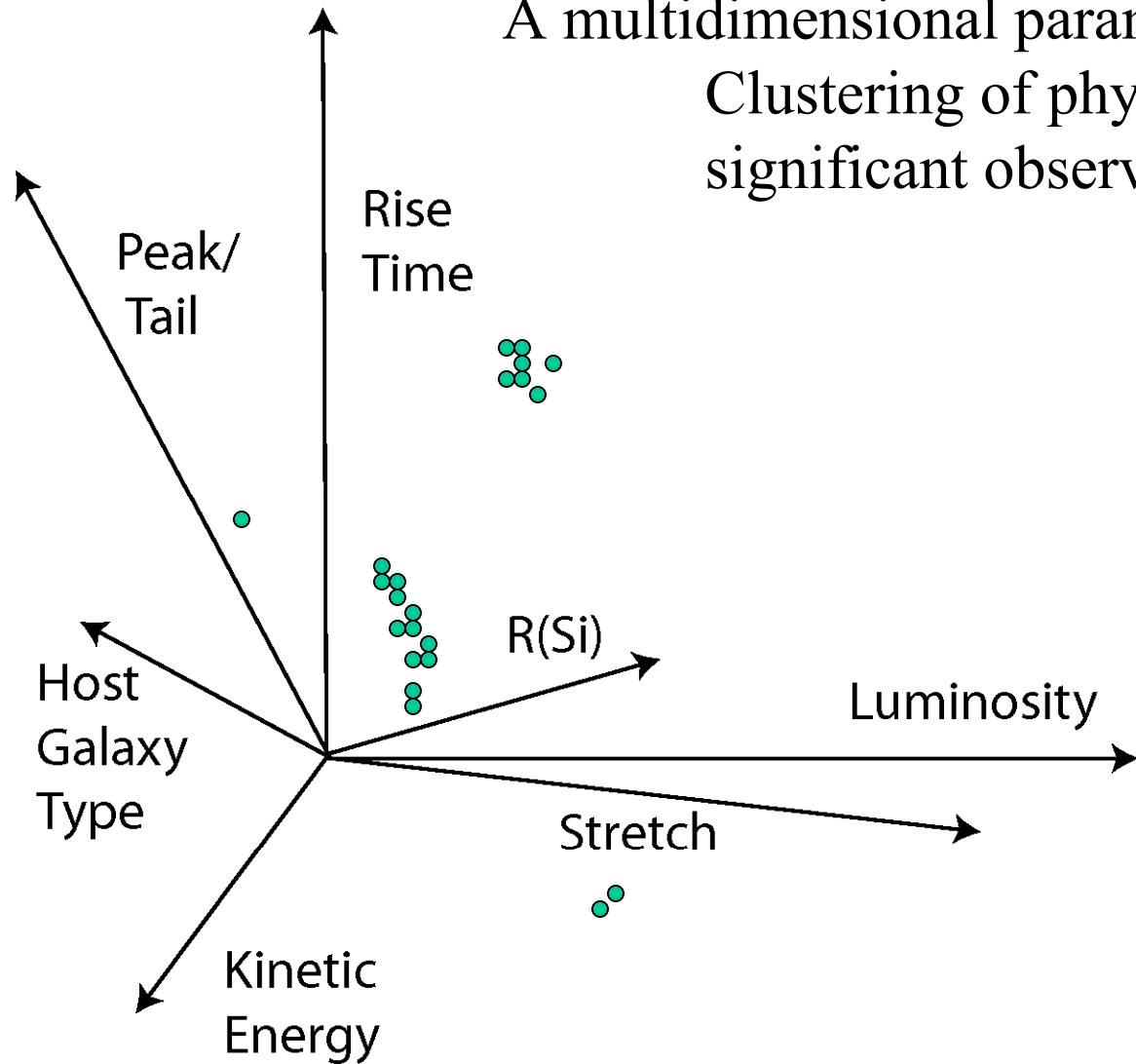
JPL

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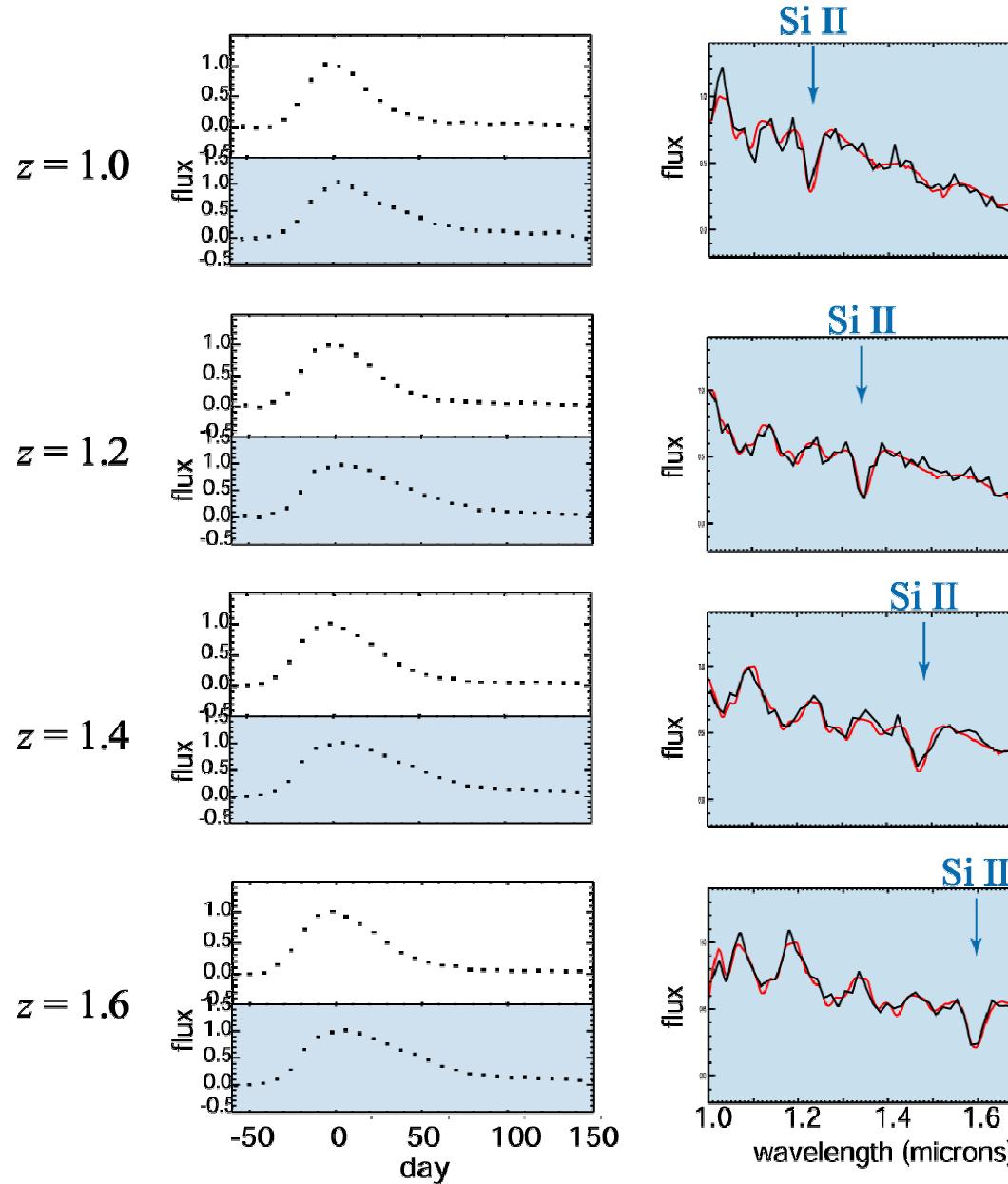


[†]Institutional affiliation

A multidimensional parameter space:
Clustering of physically
significant observables



SNAP: Observing supernovae with lightcurves and spectra



SNAP Surveys

Survey	Area(sq.deg)	Depth(AB mag)	n _{gal} (arcmin ⁻²)	N _{gal}
Deep/SNe	15	30.3	250	10 ⁷
Wide	1000	28.0	100	10 ^{8.5}
Panoramic	7000-10000	26.7	40-50	10 ⁹

Synergy of Supernovae + Weak Lensing

- Comprehensive: no external priors required!
- Independent test of flatness to 1-2%
- Complementary (SNe + WL only): conservative:

w_0 to ± 0.05 , variation w' to ± 0.12 (*with systematics*) Λ model

w_0 to ± 0.03 variation w' to ± 0.06 (*with systematics*) SUGRA model

Adding panoramic survey and better systematics:

w_0 to ± 0.03 , variation w' to ± 0.06 (*with systematics*) Λ model

w_0 to ± 0.015 variation w' to ± 0.03 (*with systematics*) SUGRA model

Baryon Oscillations:

would need $R > \sim 250$ to do the radial Baryon Oscillations, but get tangential Baryon Oscillations “**for free**” with Wide or Panoramic Survey

DOE/NASA Joint Dark Energy Mission

Science Definition Team

Science Co-chair	Albrecht, Andy	UC-Davis	Science Co-chair	Griest, Kim	UCSD
	Barish, Barry	CalTech		Kirshner, Robert	Harvard
	Baltay, Charlie	Yale		Lauer, Tod	NOAO
	Bennett, Chuck	GSFC		Levi, Michael	LBNL
	Bernstein, Gary	Penn		Linder, Eric	LBNL
	Caldwell, Robert	Dartmouth		Lupton, Robert	Princeton
	Cheng, Ed	Conc. Anal.		Moos, Warren	JHU
	Deustua, Susana	AAS		Morse, Jon	ASU
	Donahue, Megan	MSU		Perlmutter, Saul	UCB/LBNL
	Eisenstein, Dan	Arizona		Rauscher, Bernie	GSFC
	Ellis, Richard	CalTech		Riess, Adam	STScI
	Freedman, Wendy	Carnegie Obs.	Agency Co-chair	Salamon, Michael	NASA
	Frieman, Josh	FNAL		Seiffert, Mike	JPL
	Gardner, Jon	GSFC	Agency Co-chair	Turner, Kathy	DOE
	Glazebrook, Karl	JHU		Wheeler, Craig	Texas-Austin
				Wright, Ned	UCLA

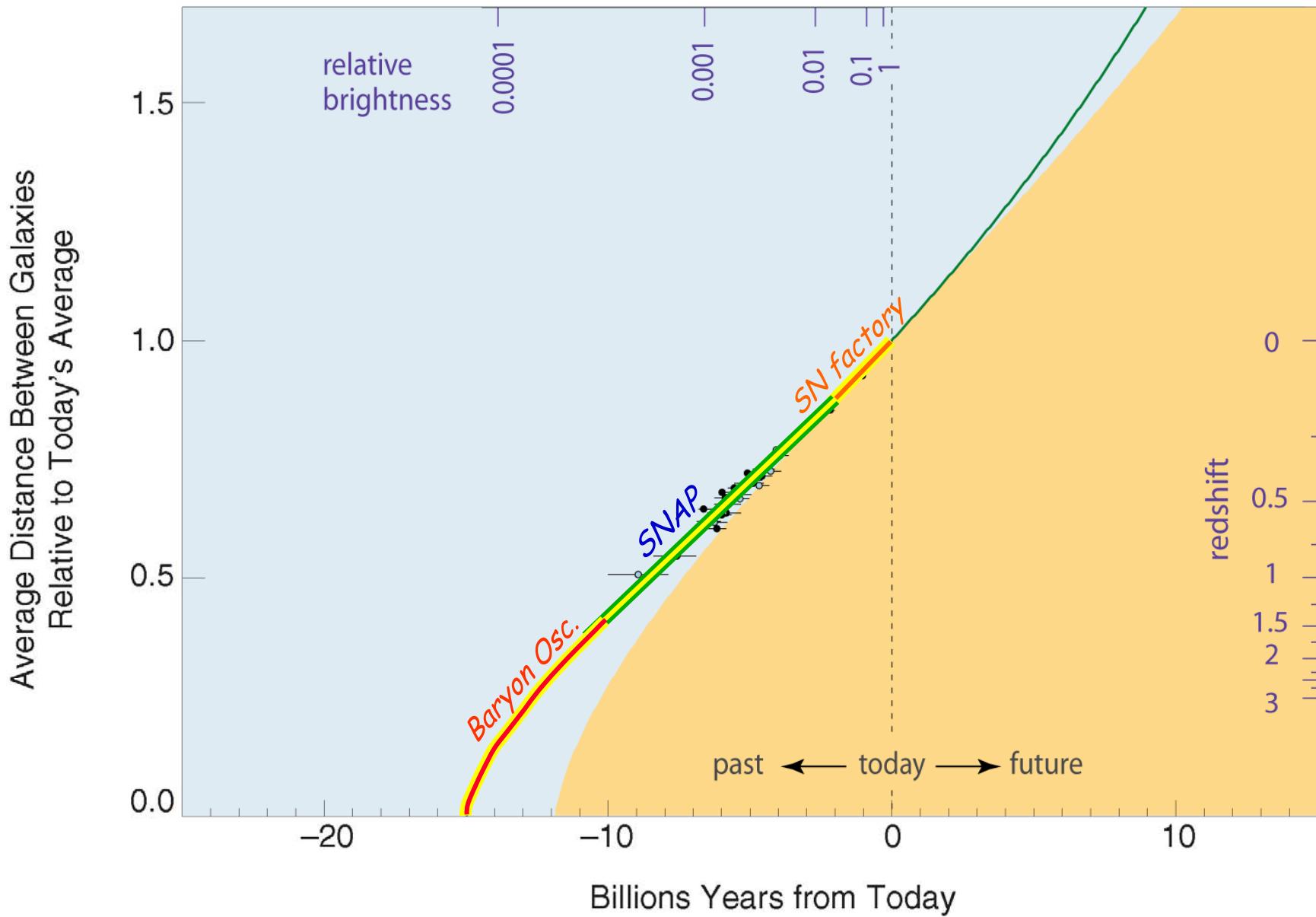
HOUSE COMMITTEE ON RULES

**CONFERENCE REPORT ON H.R. 2419, ENERGY AND
WATER DEVELOPMENT APPROPRIATIONS ACT, 2006 -
- (House of Representatives - November 07, 2005)**

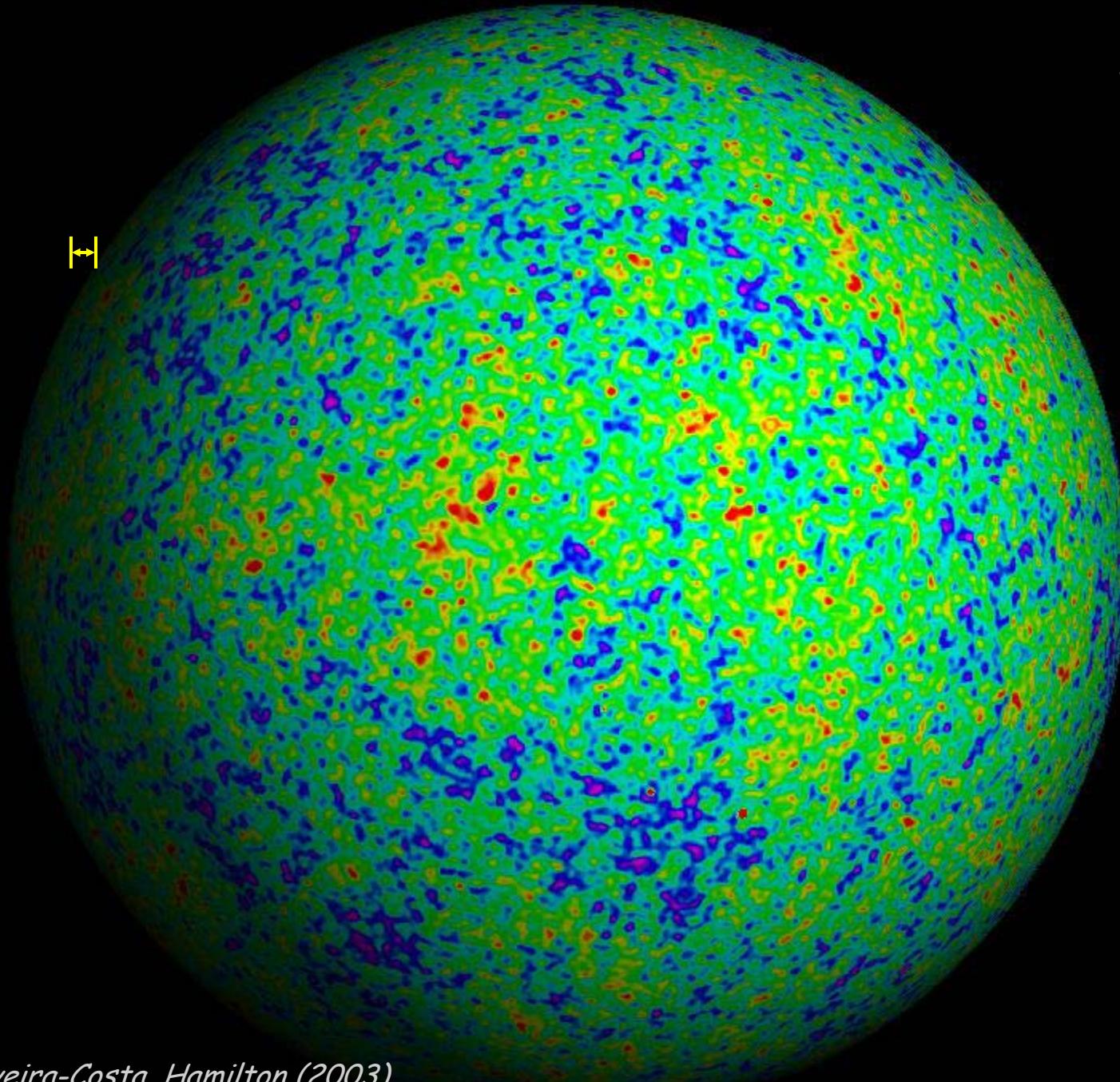
[Page: H9813] ---

“High Energy Physics.--The conference agreement provides \$723,933,000 for high energy physics research. The control level is at the High Energy Physics level. An additional \$10,000,000 is provided for research on the international linear collider and for upgrades to the neutrino research program. The conferees support the DOE/NASA Joint Dark Energy Mission (JDEM) and encourage the Department to move JDEM forward aggressively to accomplish this important research.”

Expansion History of the Universe



WMAP

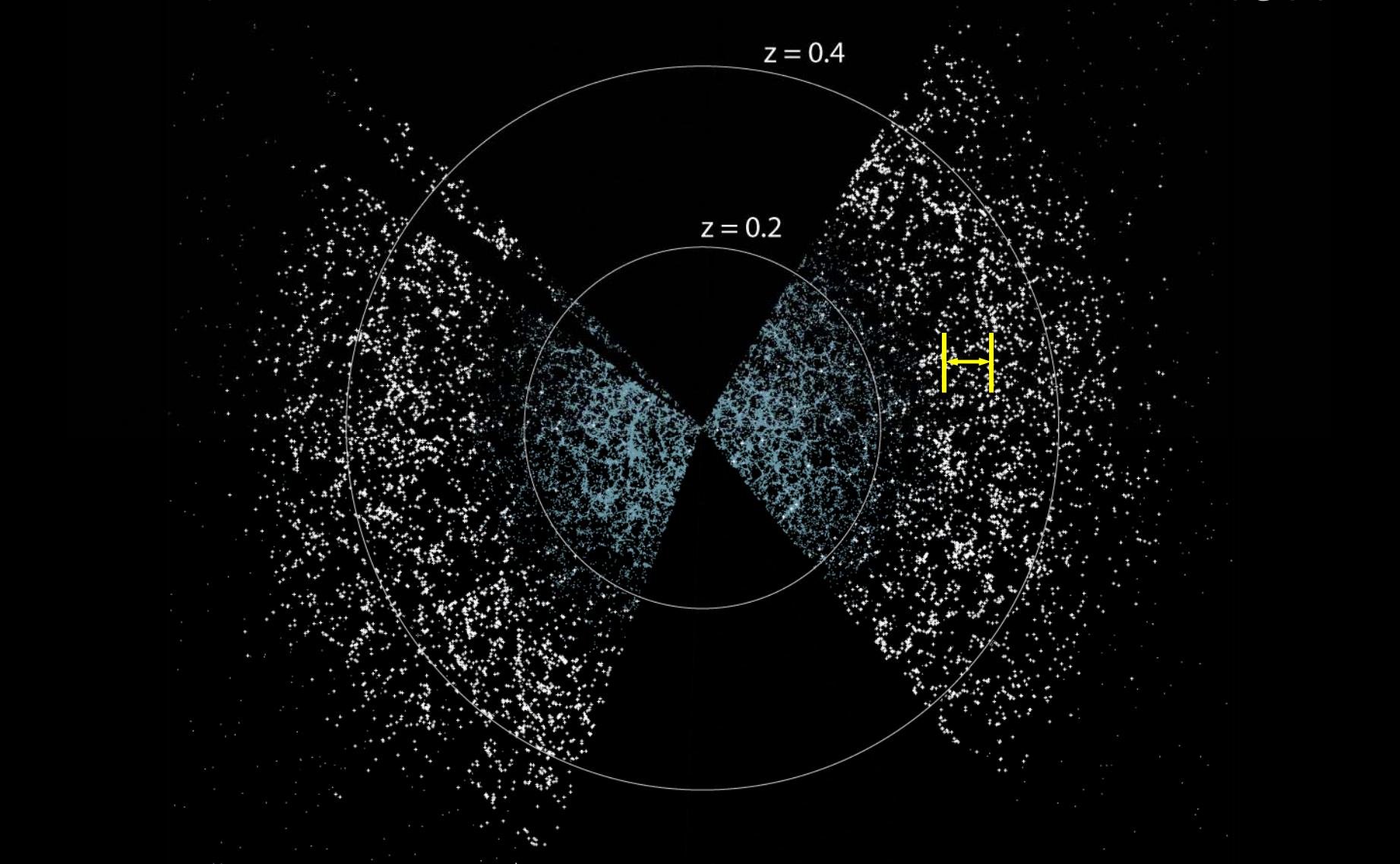


Tegmark, Oliveira-Costa, Hamilton (2003)

SDSS

$z = 0.4$

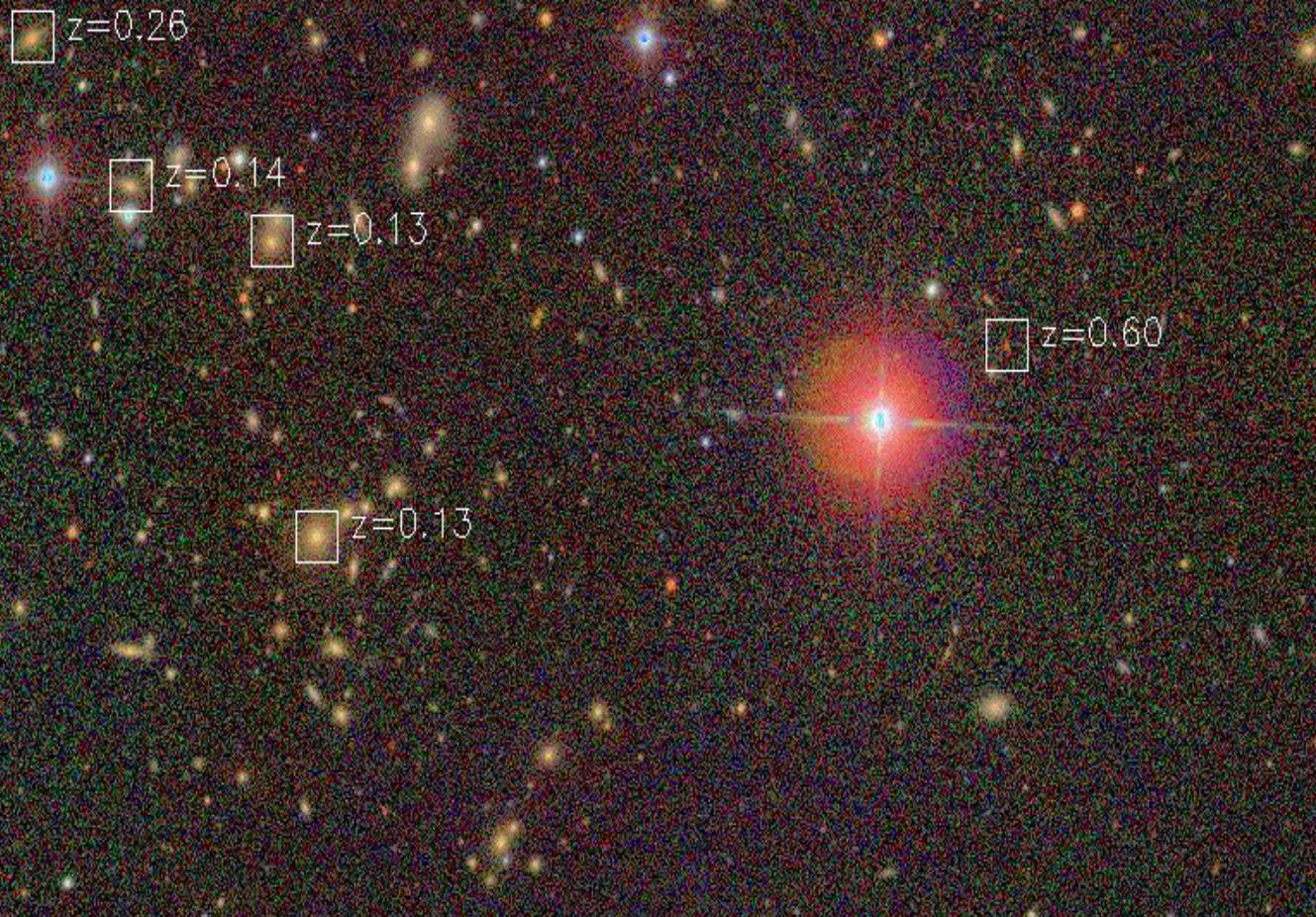
$z = 0.2$



Baryon acoustic oscillations: The tool is large galaxy redshift surveys.

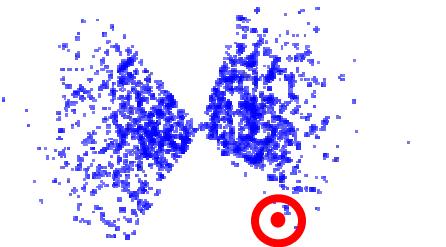
Luminous Red Galaxies are the brightest + reddest galaxies in the Universe.

Easily seen to $z=0.6$ for $M < -21$ in SDSS.

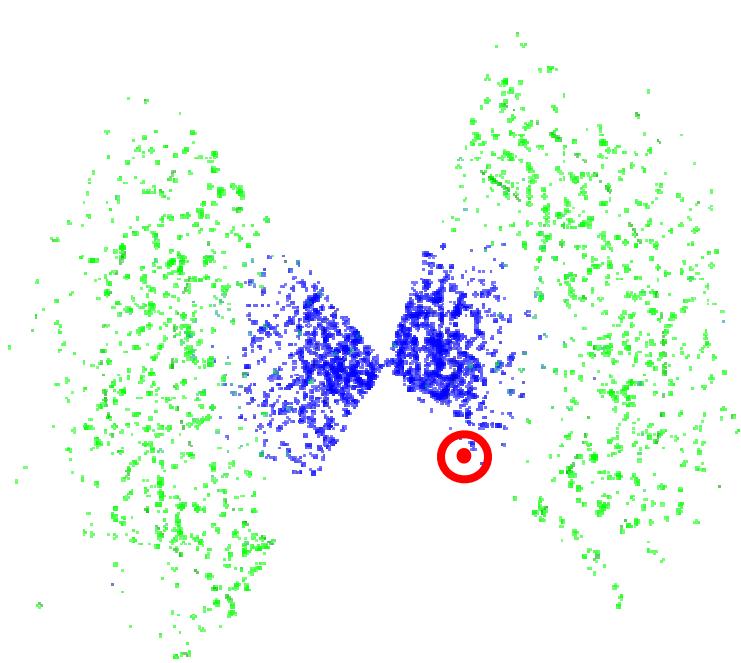


Baryon acoustic oscillations: The tool is large galaxy redshift surveys.

SDSS main survey
(too small!)

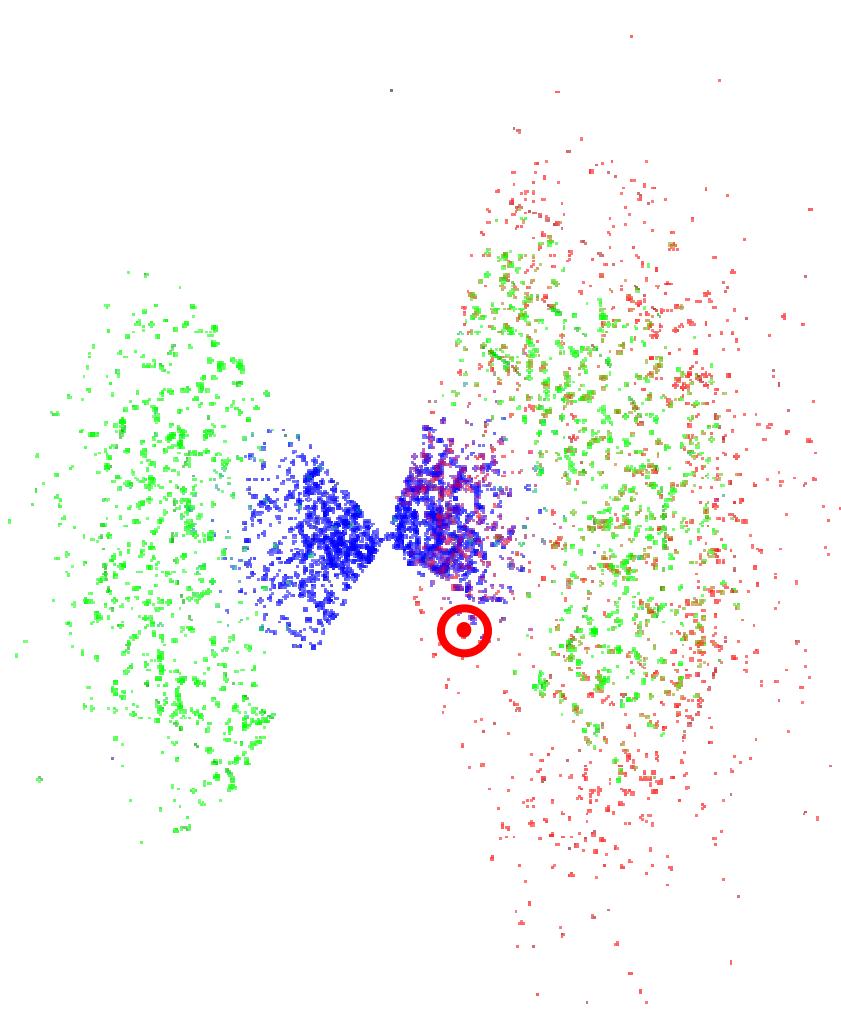


Baryon acoustic oscillations: The tool is large galaxy redshift surveys.



SDSS main survey
(too small!)
SDSS red galaxies

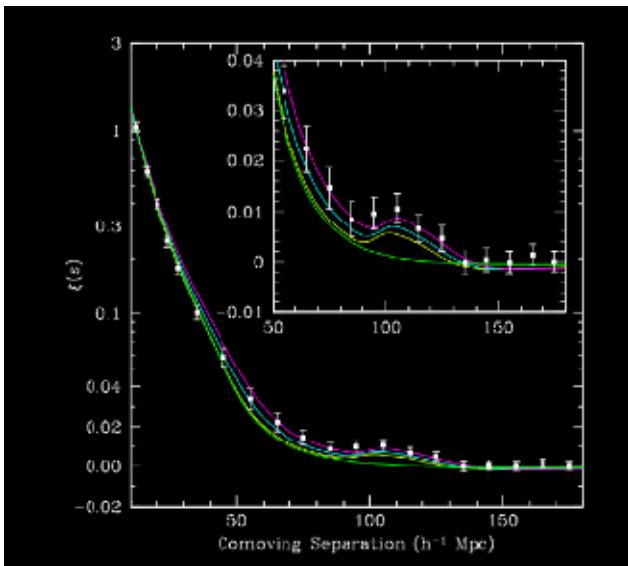
Baryon acoustic oscillations: The tool is large galaxy redshift surveys.



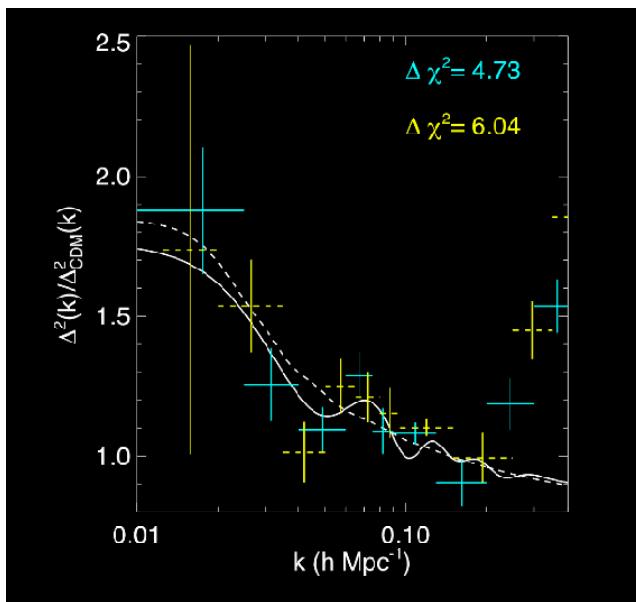
SDSS main survey
(too small!)
SDSS red galaxies

SDSS red galaxies
(photo-z only)

Baryon acoustic oscillations: First Results!

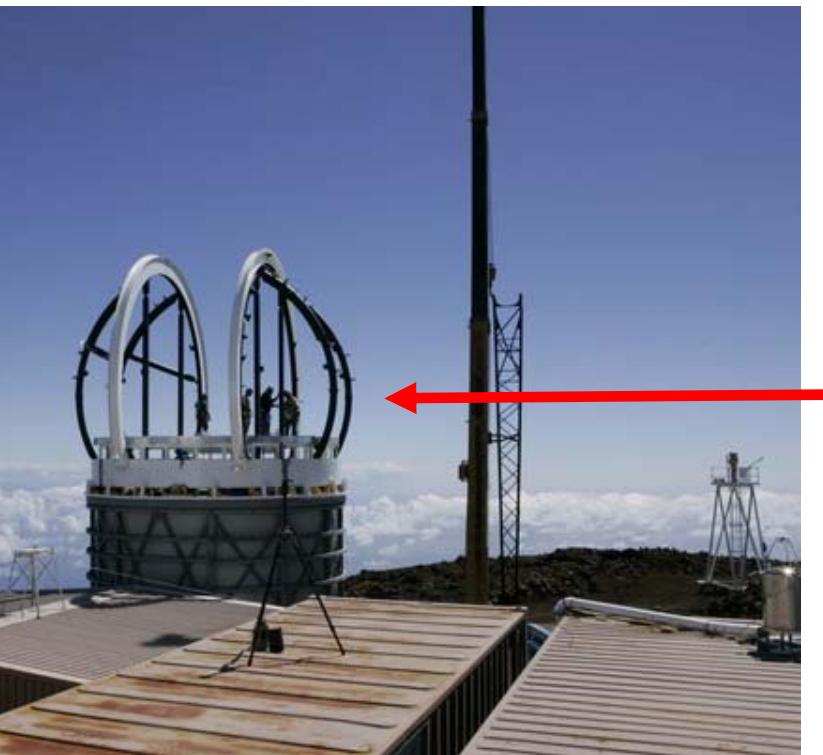


Eisenstein et al. 2005
SDSS spectro-z
40,000 red galaxies
 $0.15 < z < 0.40$
3.5-sigma detection



Padmanabhan & Schlegel 2005
SDSS photo-z (less accurate)
900,000 red galaxies
 $0.15 < z < 0.60$
2.5-sigma detection

Baryon acoustic oscillations: Future Results??



- 2006: Double volume of SDSS/LRG photo-z survey at $z < 0.4$
--> 2 million galaxies
- 2007: Double volume of SDSS/LRG spectro-z survey at $z < 0.6$
--> 100,000 galaxies
- 2008: First results from PanSTARRS survey using photo-z's



- 2010: First results possible from Thousand Points of Light at Lick spectro-z survey at $0 < z < 1.1$
- 2012: First results possible from next-gen survey at Keck $2.2 < z < 3.2$
- 2012: SNAP sat. fills the gap using photo-z survey at $1.1 < z < 2.2$

Now



5 years from now

Ground

SN Factory

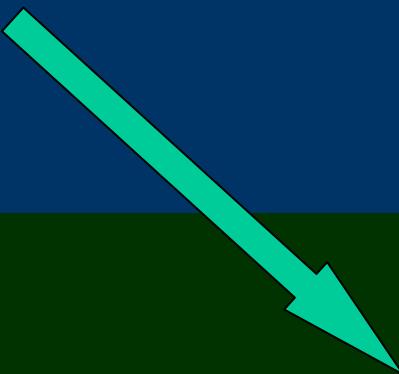
SNLS

Subaru SNe

Baryon Acoustic
Oscillations

Space

HST Cluster SNe



SNAP

Expansion History of the Universe

